Bacteria TMDL Development in Red Bank Creek and Machipongo River, Virginia

Prepared for:
Virginia Department of Environmental Quality

Submitted by:
MapTech, Inc.
Submitted:
August 15, 2013

MapTech, Inc.
3154 State Street
Blacksburg, VA 24060
(540) 961-7864

New River-Highlands RC&D

New River Highlands RC&D
325 East Main Street, Suite E-2
Wytheville, VA 24382

ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ, Tidewater Regional Office

Accomack-Northampton Planning District Commission

Accomack County Planning Department

Northampton County Planning Department

Virginia Department of Health, Division of Shellfish Sanitation

Watershed citizens

Eastern Shore Health District

NRCS – Accomack

Eastern Shore Soil and Water Conservation District

Virginia Cooperative Extension - Virginia Tech

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EXECUTIVE SUMMARY

Background and Applicable Standards

There are seven (7) different impairment segments in this study area (**Table ES. 1**). The impaired segments are on the following streams: Red Bank Creek, Red Bank Creek X-Tributary and Machipongo River. In the sections below, each impaired segment is described. The impaired segments are listed on Virginia's 303(d) list for various violations including: the *E. coli* bacteria standard, the *enterococcus* bacteria standard, the aquatic life use of the General Standard, and the shellfish harvesting use fecal coliform bacteria standard.

For modeling purposes, the impaired segments within the Red Bank Creek and Machipongo River watershed were grouped into two (2) groups, called Nested TMDL Units (NTUs).

In Virginia, once a water body violates a given standard, a Total Maximum Daily Load (TMDL) must be developed. The TMDL is a pollution budget that determines the amount of pollutant the water body can receive in a given period of time and still meet the intended standard.

TMDL Endpoint and Water Quality Assessment

A careful examination of the aquatic life use impairment due to low dissolved oxygen concentrations in four of the segments concluded the violations were due to natural conditions (MapTech, Inc., 2013). Consequently, a dissolved oxygen TMDL was not needed at this time. Thus, this TMDL is being developed for the remaining impairments which are due to bacteria.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* and *enterococci* standards. For this TMDL development, the in-stream *E. coli* target is a geometric mean not exceeding 126 cfu/100 mL, and the in-stream *enterococci* target is a geometric mean not exceeding 35 cfu/100 mL. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* and *enterococci* values.

In the TMDL development for the condemnation zones, the VDH standards for meeting the shellfish harvesting use are: a 30-month geometric mean of 14 MPN (most probable number) and a 30-month 90^{th} percentile of 49 MPN.

Table ES. 1 Impairments within the Red Bank Creek and Machipongo River watersheds included in this study.

NTU	**Stream Name** Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2010 SquareMiles**	**2010 Listing Violation%**	**Impairment Location Description**
65.1	**Red Bank Creek** VAT-D04E_RBC02A08	*Enterococci* Shellfish	2008 2006	0.01	33.3 #095-192 A	Approximately 0.37 mi. from UT (XDF) to boat dock.
65.1	**Red Bank Creek** VAT-D04E_RBC03A08	*Enterococci* Shellfish Dissolved Oxygen	2008 2006 2008	0.00	33.3 #095-192 A 37.5	At the end of Route 617 at Public Boat Landing.
65.1	**Red Bank Creek** VAT-D04E_RBC04A08	*Enterococci* Dissolved Oxygen	2008 2008	0.01	33.3 37.5	From the Little Stony Creek confluence downstream to the Staunton Creek confluence.
65.1	**Red Bank Creek** VAT-D04E_RBC01A08	Dissolved Oxygen Shellfish	2008 2006	0.00	33 #095-192 A	Near Brick House Neck at the end of tidal waters downstream to the confluence of unnamed tributary (XDF).
65.1	**Red Bank Creek** VAT-D04R_RBC01A04	*Fecal coliform*	2006	1.27 river miles	67	The area from the headwaters downstream to the end of tidal waters. Southeast of Marionville.
65.1	**Unnamed Tributary to Redbank Creek** VAT-D04E_XDF01A04	Dissolved Oxygen Shellfish	2004 2006	0.01	50 #095-192 A	Begins southeast of Marionville, near Brick House Neck from first branching of creek (RM 0.3) downstream to confluence with Red Bank Creek.
65.2	**Machipongo River** VAT-D04E_MAC01A00	*Enterococci* Shellfish	2008	0.67	13.3 #096-218 A	Located east of Exmore and extends from end of tidal waters downstream to 0.5 mi. south of Rt. 182 crossing (minus area at mouth of Greens Creek).

Enteroccoci based on the instantaneous *enterococci* standard of 104 cfu/100mL.
Fecal coliform based on the instantaneous fecal coliform standard of 400 cfu/100mL.
Dissolved oxygen impairments have been determined to be due to natural conditions.

Source Assessment

Sources of bacteria were identified and quantified in the Red Bank Creek and Machipongo River watersheds. Sources included only nonpoint sources. The quantification of sources is important to determine the baseline of current conditions that is causing the impairment. Sources of bacteria included human, livestock, wildlife, pets, as well as permitted nonpoint sources.

Modeling Procedures

Computer modeling is used to relate the sources on the ground to the water quality in the streams and rivers. This is important since not every colony of bacteria in the Red Bank Creek and Machipongo River watersheds ends up in the streams and rivers. The computer models help quantify the portion of bacteria within the Red Bank Creek and Machipongo River watersheds that ends up in the stream.

The computer modeling process consists of several steps. First, the characteristics of the drainage area including land use, slopes, stream network, soil properties, are entered into the model. The quantities of bacteria are also entered into the model. A process known as calibration is then conducted by comparing model simulations with monitored field data. Model parameters are adjusted during calibration to minimize the error between simulated and monitored values. This process is conducted for hydrology (flow) as well as water quality. Once the model is calibrated, it is then used to determine the existing water quality conditions in the study area and may be used to determine the reductions necessary to meet the water quality standard or endpoint.

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform loads. In the Red Bank Creek and Machipongo River watersheds, the upstream areas are riverine segments, while downstream segments are tidally influenced and contain more swampland. The Steady State Tidal Prism Model was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. For purposes of modeling the Red Bank Creek and Machipongo River watersheds, inputs to streamflow and in-stream fecal bacteria, the drainage area was divided into nine (9) subwatersheds.

The absence of a flow-gauging station in the watershed led to the use of a reference watershed approach to estimate the hydrology in the study area. The reference was Nassawadox Creek watershed.

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct sources of uncontrolled discharges, direct deposition by wildlife, direct deposition by livestock, and direct inputs from sewer overflows. Contributions from all of these sources were updated to current conditions to establish existing conditions for the watershed.

Load Allocation Scenarios

The next step in the TMDL processes was to reduce the various source loads to levels that would result in attainment of the water quality standards or endpoints. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. The final TMDL information is shown in **Table ES. 2**.

The final bacterial TMDLs for the Red Bank Creek and Machipongo River watershed include 100% reductions in straight pipes.

Table ES. 2 Average annual in-stream cumulative pollutant loads modeled after allocation in the Red Bank Creek and Machipongo River watersheds impairments.

Pollutant	Units	Impairment	WLA[1]	LA	MOS	TMDL	Existing Load	Percent Reduction[2]
E. coli	cfu/yr	**Red Bank Creek, Riverine**	1.08E+08	1.08E+10	*Implicit*	1.09E+10	**2.19E+10**	**99.5**
Fecal coliform	cfu/yr	**Red Bank Creek, Shellfish**	5.10E+11	5.10E+13	*Implicit*	5.15E+13	**2.19E+14**	**99.8**
Enterococci	cfu/yr	**Red Bank Creek, Estuarine**	3.93E+06	3.93E+08	*Implicit*	3.97E+08	**4.49E+08**	**99.1**
Fecal coliform	cfu/yr	**Machipongo River, Shellfish**	2.04E+12	2.04E+14	*Implicit*	2.06E+14	**1.76E+15**	**99.9**
Enterococci	cfu/yr	**Machipongo River, Estuarine**	9.03E+06	9.03E+08	*Implicit*	9.12E+08	**1.14E+09**	**99.2**

[1] WLA by permit can be found in the corresponding allocation chapters.
[2] Percent reduction does not include the Margin of Safety (MOS).

Implementation

The goal of the TMDL program is to establish a path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the first phase of that effort for the impairments in the Red Bank Creek and Machipongo River watershed. The next step will be development of a TMDL implementation plan (IP), required by Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA). The final step is to implement the TMDL IPs and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned, a new designated use, or a subcategory of a use, the current designated use must be removed. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Public Participation

During development of the TMDL for the impairments in the Red Bank Creek and Machipongo River watersheds study area, public involvement was encouraged through a first public meeting (12/13/2012), and a final public meeting (08/15/2013). An introduction of the agencies involved, an overview of the TMDL process, details of the pollutant sources, and the specific approach to developing the Red Bank Creek and Machipongo River watersheds TMDLs were presented at the first public meeting. Public understanding of and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period after each public meeting. Written comments were addressed in the final document.

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1. INTRODUCTION

1.1. Regulations Background

The Clean Water Act (CWA) that became law in 1972 requires that all U.S. streams, rivers, and lakes meet certain water quality standards. The CWA also requires that states conduct monitoring to identify waters that are polluted or do not otherwise meet standards. Through this required program, the state of Virginia has found that many stream segments do not meet state water quality standards for protection of the six beneficial uses: recreation/swimming, aquatic life, wildlife, fish consumption, shellfish consumption, and public water supply (drinking).

When streams fail to meet standards, the stream is "listed" in the current Section 303(d) report as requiring a Total Maximum Daily Load (TMDL). Section 303(d) of the CWA and the U.S. Environmental Protection Agency's (EPA) Water Quality Management and Planning Regulation (40 CFR Part 130) both require that states develop a Total Maximum Daily Load (TMDL) for each pollutant. A TMDL is a "pollution budget" for a stream; that is, it sets limits on the amount of pollution that a stream can tolerate and still maintain water quality standards. In order to develop a TMDL, background concentrations, point source loadings, and nonpoint source loadings are considered. A TMDL accounts for seasonal variations and must include a margin of safety (MOS).

Once a TMDL is developed and approved by EPA, measures must be taken to reduce pollution levels in the stream. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states in section 62.1-44.19:7 that the *"Board shall develop and implement a plan to achieve fully supporting status for impaired waters"*. The TMDL Implementation Plan (IP) describes control measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), which should be implemented in a staged process. Through the TMDL process, states establish water-quality based controls to reduce pollution and meet water quality standards.

1.2. *Red Bank Creek and Machipongo River Watershed Characteristics*

The Red Bank Creek and Machipongo River watersheds (USGS Hydrologic Unit Code 02080110) is located in Accomack and Northampton Counties of Virginia's Eastern Shore. This watershed drains directly to the Atlantic Ocean. The location of the watershed is shown in **Figure 1.** 1. The drainage area flowing into the most downstream impairment in this project is approximately 16,376 acres split between Red Bank Creek (2,158 acres) and Machipongo River (14,218 acres).

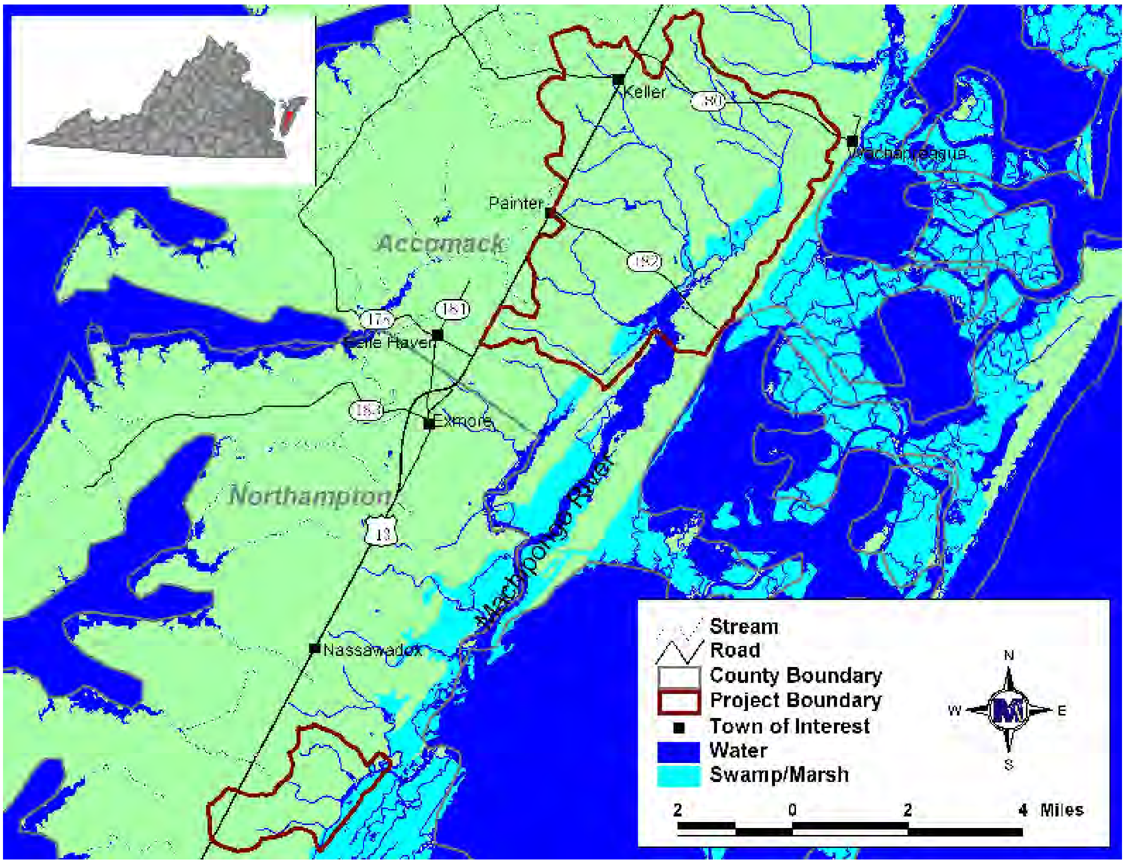

Figure 1. 1 Location of the Red Bank Creek and Machipongo River watersheds.

The Red Bank Creek and Machipongo River watersheds are located within the level III Middle Atlantic Coastal Plain (63) ecoregion. The Middle Atlantic Coastal Plain is low, nearly flat plain, with many swampy or marshy areas. Forest cover in the region is predominantly loblolly-shortleaf pine with patches of oak, gum, and cypress near major streams. Poorly drained soils are common especially in lowest areas and elevations range from 0 to 100 feet (http://www.eoearth.org/article/Ecoregions_of_Delaware%2C_Maryland%2C_Pennsylvania%2C_Virginia%2C_and_West_Virginia_%28EPA%29).

As for the climatic conditions in the Red Bank Creek and Machipongo River watersheds, during the period from December 1955 to December 2011 Painter 2 W, Virginia (NCDC station# 446475) received an average annual precipitation of 43.89 inches, with 53% of the precipitation occurring during the May through October growing season (SERCC, 2012). Average annual snowfall is 9.4 inches, with the highest snowfall occurring during January (SERCC, 2012). The highest average daily temperature of 86.7 ºF occurs in July, while the lowest average daily temperature of 29.4 ºF occurs in January (SERCC, 2012).

Land use in the study area was characterized using the National Land Cover Database 2001 (NLCD). The drainage area is predominantly wetlands which cover 42% of the area. Cropland is next most important covering 24%. Forest and pasture/hay land cover equal amounts totaling 25% of the drainage area. Developed, water, commercial, and barren land uses account for the remainder of the study area.

1.3. Red Bank Creek and Machipongo River Watershed Impairments

There are seven (7) different impairment segments in this study area which are listed in **Table 1.1**. The impaired segments are on the following streams: Red Bank Creek, Red Bank Creek X-Trib, and Machipongo River. In the sections below, each impaired segment is described. The impaired segments are listed on Virginia's 303(d) list for various violations including: the fecal coliform bacteria standard, the *enterococcus* bacteria standard, the aquatic life use of the General Standard, and the Shellfish harvesting use standard. A careful examination of the aquatic life use impairment due to low dissolved oxygen concentrations in four of the segments concluded the violations were due to natural conditions (MapTech, Inc., 2013). Consequently, a dissolved oxygen TMDL was not needed at this time. Thus, this TMDL is being developed for the remaining impairments which are due to bacteria.

For modeling purposes, the impaired segments within the Red Bank Creek and Machipongo River watersheds were grouped into two (2) groups, called Nested TMDL Units (NTUs).

1.3.1. Red Bank Creek (NTU 65.1) (VAT-D04E_RBC02A08)

Red Bank Creek in Northampton County flows east before the Phillips Creek confluence. Impairments in the Red Bank Creek watershed are mapped in **Figure 1. 2** and **Figure 1. 3.**

This impaired portion of Red Bank Creek, approximately 0.37 mi. from an unnamed tributary (XDF) to a boat dock (0.01 square miles), was placed on the 2010 303(d) list as impaired for not supporting the recreation/swimming use. VADEQ *enterococci* monitoring resulted in a 33% bacteria standard violation rate in the 2010 305(b) assessment. This segment was also listed on the 2010 303(d) list for not supporting shellfish harvesting use. The Division of Shellfish Sanitation (DSS) issued a shellfish condemnation (# 095-192 A, effective 2005-9-21).

1.3.2. Red Bank Creek (NTU 65.1) (VAT-D04E_RBC03A08)

Located at the end of Route 617 at Public Boat Landing (0.00 square miles), this segment was listed as impaired on the 2010 303(d) list for not supporting the recreation/swimming use. VADEQ *enterococci* monitoring resulted in a 33% bacteria standard violation rate in the 2010 305(b) assessment.

This segment is listed on the 2010 303(d) list for not supporting the shellfish harvesting use. The DSS issued a shellfish condemnation (# 095-192 A, effective 2005-9-21).

1.3.3. Red Bank Creek (NTU 65.1) (VAT-D04E_RBC04A08)

The lower segment of Red Bank Creek from downstream to confluence with Phillips Creek (0.01 square miles), was listed as impaired on the 2010 303(d) list for not supporting the recreation/swimming use. VADEQ *enterococci* monitoring resulted in a 33% bacteria standard violation rate in the 2010 305(b) assessment.

1.3.4. Red Bank Creek (NTU65.1) (VAT-D04E_RBC01A08)

Red Bank Creek near Brick House Neck at the end of tidal waters downstream to the confluence of unnamed tributary (XDF) (0.00 square miles) was listed as impaired on the 2010 303(d) list for not supporting the shellfish harvesting use. The DSS issued a shellfish condemnation (# 095-192 A, effective 2005-9-21).

1.3.5. Red Bank Creek (NTU 65.1) (VAT-D04R_RBC01A04)

This segment in Northampton County is the headwaters of Red Bank Creek and downstream to the end of tidal waters. It is southeast of Marionville, VA. This segment was listed on the 2010 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring resulted in a 67% bacteria standard violation rate in the 2010 305(b) assessment.

1.3.6. Unnamed Tributary to Red Bank Creek (NTU 65.1) (VAT-D04E_XDF01A04)

This unnamed tributary in Northampton County flows east before its confluence with Red Bank Creek. The segment begins southeast of Marionville, near Brick House Neck from first branching of creek (RM 0.3) downstream to confluence with Red Bank Creek (0.01 square miles). This segment was listed on the 2010 303(d) list for not supporting the shellfish harvesting use. The DSS issued a shellfish condemnation for the area (# 095-192 A, effective 2005-9-21).

1.3.7. Machipongo River (NTU 65.2) (VAT-D04E_MAC01A00)

Machipongo River in Accomack and Northampton Counties flows south before it's confluence with the Atlantic Ocean. Impairments are mapped in **Figure 1. 2** and **Figure 1. 3.** The segment is located east of Exmore and extend from the end of tidal waters downstream to 0.5 mi. south of the Rt. 182 crossing (minus area at mouth of Greens Creek) (0.67 square miles). The segment was listed as impaired on the 2010 303(d) list of impaired waters for not supporting the recreation/swimming use. VADEQ monitoring station 7-MAC008.55 had a bacteria standard violation rate of 13.3% in the 2010 assessment. This segment is listed on the 2010 303(d) list for not supporting the shellfishing use. The DSS issued Shellfish condemnation #096-218 A for the area (effective date 2006-10-10).

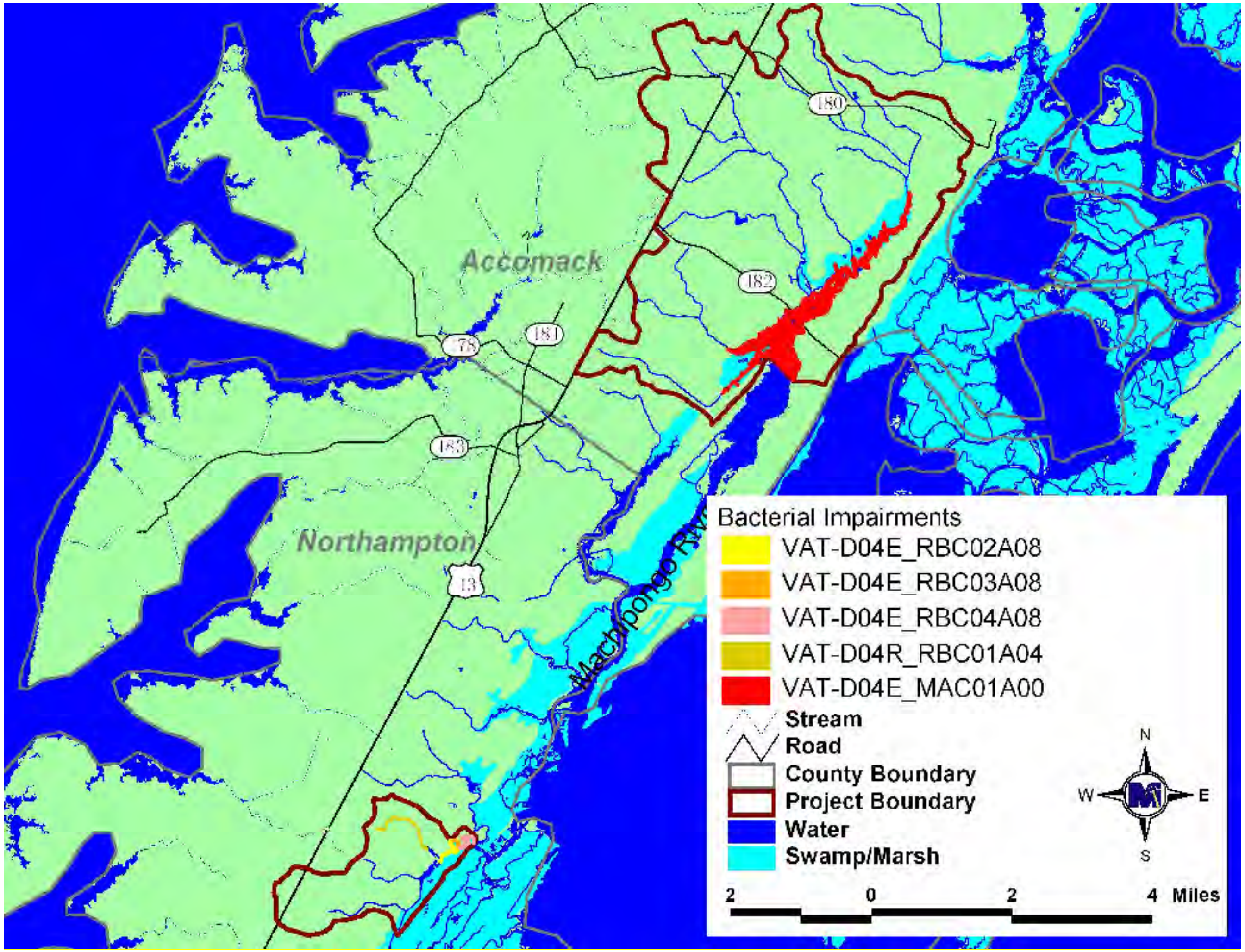

Figure 1. 2 The recreation use-impaired segments in the Red Bank Creek and Machipongo River watersheds.

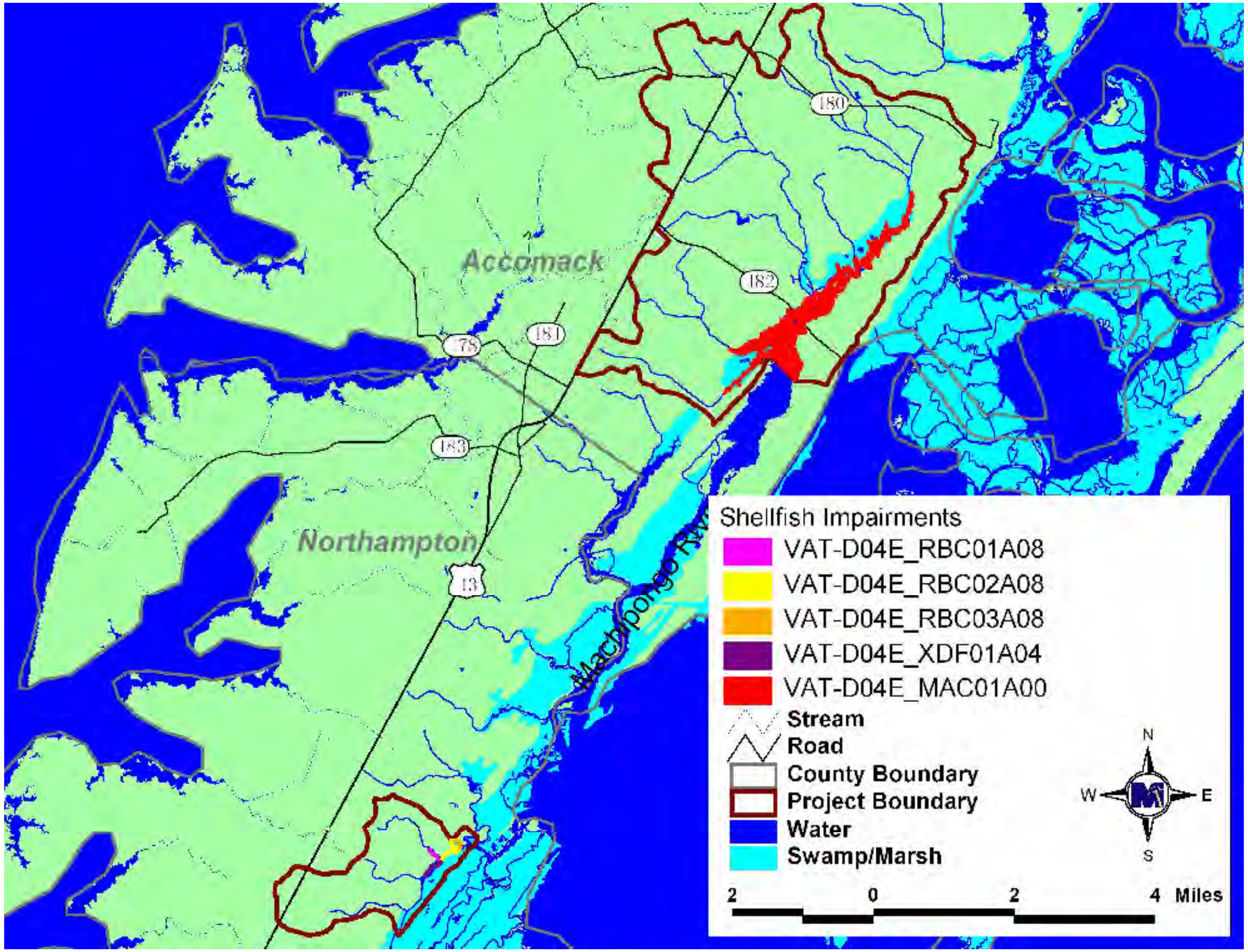

Figure 1. 3 The shellfishing use-impaired segments in the Red Bank Creek and Machipongo River watersheds.

Table 1.1 Impairments within the Red Bank Creek and Machipongo River watersheds included in this study.

NTU	**Stream Name** Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2010 Square Miles/ River Miles**	**2010 Listing Violation%**	**Impairment Location Description**
65.1	**Red Bank Creek** VAT-D04E_RBC02A08	*Enterococci* Shellfish	2008 2006	0.01	33.3 #095-192 A	Approximately 0.37 mi. from UT (XDF) to boat dock.
65.1	**Red Bank Creek** VAT-D04E_RBC03A08	*Enterococci* Shellfish Dissolved Oxygen	2008 2006 2008	0.00	33.3 #095-192 A 37.5	At the end of Route 617 at Public Boat Landing.
65.1	**Red Bank Creek** VAT-D04E_RBC04A08	*Enterococci* Dissolved Oxygen	2008 2008	0.01	33.3 37.5	From the Little Stony Creek confluence downstream to the Staunton Creek confluence.
65.1	**Red Bank Creek** VAT-D04E_RBC01A08	Dissolved Oxygen Shellfish	2008 2006	0.00	33 #095-192 A	Near Brick House Neck at the end of tidal waters downstream to the confluence of unnamed tributary (XDF).
65.1	**Red Bank Creek** VAT-D04R_RBC01A04	*Fecal coliform*	2006	1.27 river miles	67	The area from the headwaters downstream to the end of tidal waters. Southeast of Marionville.
65.1	**Unnamed Tributary to Redbank Creek** VAT-D04E_XDF01A04	Dissolved Oxygen Shellfish	2004 2006	0.01	50 #095-192 A	Begins southeast of Marionville, near Brick House Neck from first branching of creek (RM 0.3) downstream to confluence with Red Bank Creek.
65.2	**Machipongo River** AT-D04E_MAC01A00	*Enterococci* Shellfish	2008	0.67	13.3 #096-218 A	Located east of Exmore and extends from end of tidal waters downstream to 0.5 mi. south of Rt. 182 crossing (minus area at mouth of Greens Creek).

Enteroccoci - Based on the instantaneous *enterococci* standard of 104 cfu/100mL.
Fecal coliform based on the instantaneous fecal coliform standard of 400 cfu/100mL.
Dissolved oxygen impairments have been determined to be due to natural conditions.

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2. BACTERIA TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1. Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act".

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *E. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§ 301(b)(1)(A) and (B) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*
>
> ♦
>
> *H. The [State Water Quality Control] Board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*
>
> 1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
>
> 2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*

3. *Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;*

4. *Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use;*

5. *Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or*

6. *Controls more stringent than those required by §§ 301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

I. The board may not remove designated uses if:

1. *They are existing uses, unless a use requiring more stringent criteria is added; or*

2. *Such uses will be attained by implementing effluent limits required under §§ 301(b)(1)(A) and (B) and 306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control.*

2.2. Applicable Criteria for Fecal Bacteria

Virginia's current bacterial standard uses *E. coli* and *enterococci* as bacterial indicators. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals; there is a strong correlation between these and the incidence of gastrointestinal illness. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. Prior to January 2003, Virginia's water quality standard in fresh water for swimming/recreational use was based on fecal coliform rather than *E.coli.* The change was based on EPA's recommendation that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA pursued the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform.

The criteria which were used in developing the bacteria TMDL in this study are outlined in Section 9 VAC 25-260-170 and read as follows:

> *A. The following bacteria criteria (colony forming units (CFU)/100 ml) shall apply to protect primary contact recreational uses in surface waters, except waters identified in subsection B of this section:*
>
> *E.coli bacteria shall not exceed a monthly geometric mean of 126 CFU/100 ml in freshwater.*
>
> *Enterococci bacteria shall not exceed a monthly geometric mean of 35 CFU/100 ml in transition and saltwater.*
>
> 1. *See 9VAC25-260-140 C for boundary delineations for freshwater, transition and saltwater.*
> 2. *Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples.*
> 3. *If there are insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E.coli CFU/100 ml .*
> 4. *If there are insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 104 CFU/100 ml.*
> 5. *For beach advisories or closures, a single sample maximum of 235 E.coli CFU/100 ml in freshwater and a single sample maximum of 104 enterococci CFU/100 ml in saltwater and transition zones shall apply.*

For shellfish, the criteria used for developing TMDLs are outlined in 9 VAC 25-260-160 and read as follows:

> *In all open ocean or estuarine waters capable of propagating shellfish or in specific areas where public or leased private shellfish beds are present, and including those waters on which condemnation are established by the State Department of Health, the following criteria for fecal coliform bacteria shall apply:*
>
> *The geometric mean fecal coliform value for a sampling station shall not exceed an MPN (most probable number) or MF (membrane filtration using mTEC culture media) of 14 per 100 milliliters (ml). The estimated 90th percentile shall not exceed an MPN of 43 per 100 ml for a 5-tube*

> *decimal dilution test or an MPN of 49 per 100 ml for a 3-tube decimal dilution test or MF test of 31 CFU (colony forming units) per 100 ml.*

These standards are calculated using a 30-month window, which means every consecutive 30-month data group must have a geometric mean of 14 MPN or less and a 90th percentile of 49 MPN or less to meet both standards.

2.3. Selection of a Bacteria TMDL Endpoint

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the bacteria impairments in the Red Bank Creek and Machipongo River watersheds, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations. In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard.

Since modeling provided simulated output of fecal coliform concentrations at 1-hour intervals, the concentrations were used directly for shellfish impairments. For freshwater and estuarine recreation impairments the fecal coliform concentrations were translated into *E. coli* and *enterococci* concentrations, respectively. Thereupon, the in-stream targets for the TMDLs were developed.

The TMDLs for the estuarine segments of Red Bank Creek and Machipongo River VADEQ primary contact recreational use impairments were made using both the *enterococci* VADEQ geometric mean standard and the 90th percentile standard. Therefore, the in-stream *enterococci* targets for these TMDLs were a monthly geometric mean not exceeding 35 cfu/100 ml and a 90th percentile not exceeding 104 cfu/100 ml.

The TMDL for the riverine VADEQ primary contact recreational use in Red Bank Creek headwaters segment RBC01A04, was made using both the *E. coli* VADEQ geometric mean standard and the instantaneous standard. Therefore, the in-stream *E. coli* targets for this TMDL was a 30-day geometric mean not exceeding 126 cfu/100 ml and an instantaneous value not exceeding 235 cfu/100 ml.

The VDH shellfish harvesting use impairments were assessed using both the VDH fecal coliform geometric mean standard and the 90th percentile standard. Therefore, the in-stream fecal coliform targets for the VDH TMDLs were a monthly geometric mean not exceeding 14 MPN and a 90th percentile not exceeding 49 MPN.

2.4. Discussion of In-Stream Water Quality

This section provides an inventory and analysis of available, observed in-stream fecal bacteria monitoring data in the watershed of the Red Bank Creek and Machipongo River watersheds. Data from water quality stations used in the 305(b) assessment were examined. Sources of data and pertinent results are discussed.

2.4.1. Inventory of Water Quality Monitoring Data

The primary sources of available fecal bacteria information are:

- Bacteria enumerations from 2 VADEQ in-stream monitoring stations with data from September 2001 to December 2006, and
- Bacteria enumerations from 45 Virginia Department of Health (VDH) monitoring sites with data from January 2000 to July 2012.

2.4.2. VADEQ and VDH-DSS Water Quality Monitoring for TMDL Assessment

Data from in-stream water samples, collected at VADEQ monitoring stations from September 2001 to December 2006 (**Figure 2.1**) were analyzed for e*nterococci* (**Table 2.1**). Samples were taken for the express purpose of determining compliance with the state instantaneous standard limiting *enterococci* concentrations to 104 cfu/100 mL or less. As a matter of economy, samples showing *enterococci* concentrations below 25 cfu/100 mL or in excess of 2,000 cfu/100 mL were not analyzed further to determine the precise concentration of *enterococci*. The result is that reported values of 25 cfu/100 mL most likely represent concentrations below 25 cfu/100 mL, and reported concentrations of 2,000 cfu/100 mL most likely represent concentrations in excess 2,000 cfu/100 mL.

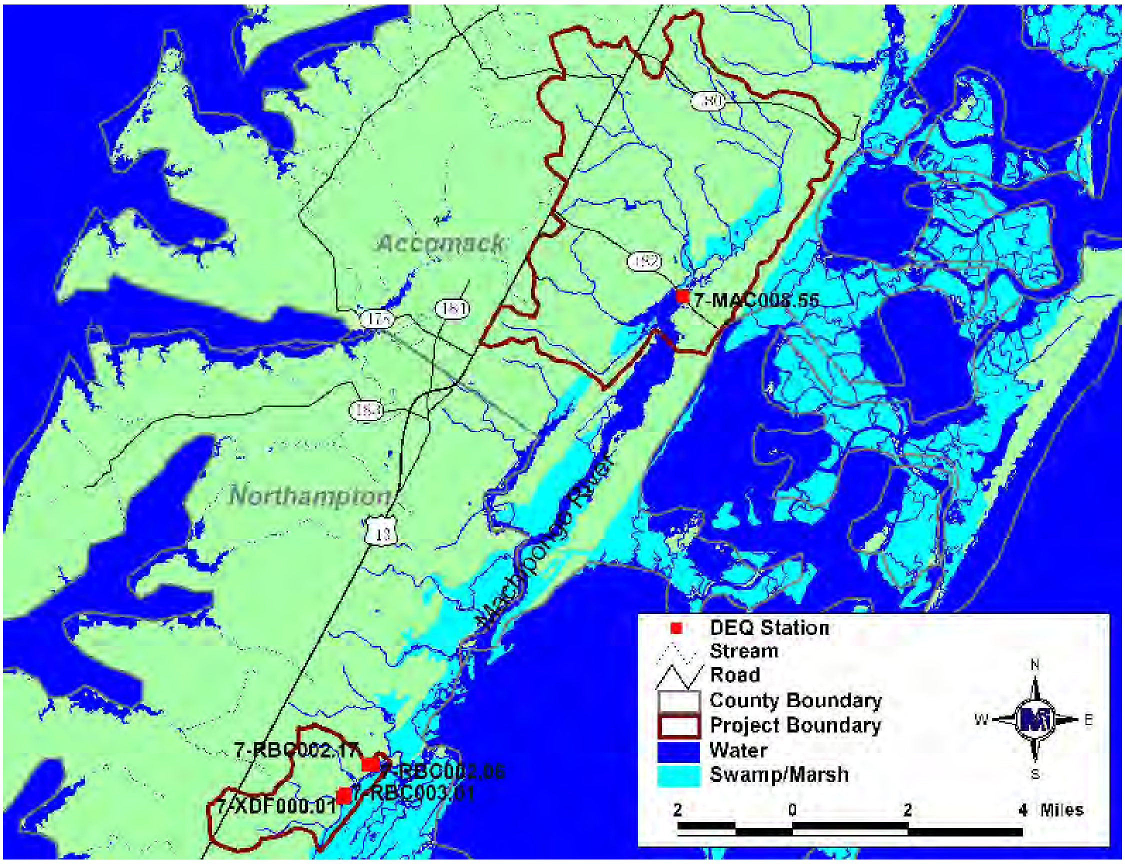

Figure 2.1 Location of VADEQ water quality monitoring stations in the Red Bank Creek and Machipongo River watersheds.

Data from in-stream monitoring water samples, collected at VDH monitoring sites from January 2000 to July 2012 (**Figure 2.2**) were analyzed for fecal coliform (**Table 2.2**). Samples were taken for the express purpose of determining compliance with shellfish consumption requirements.

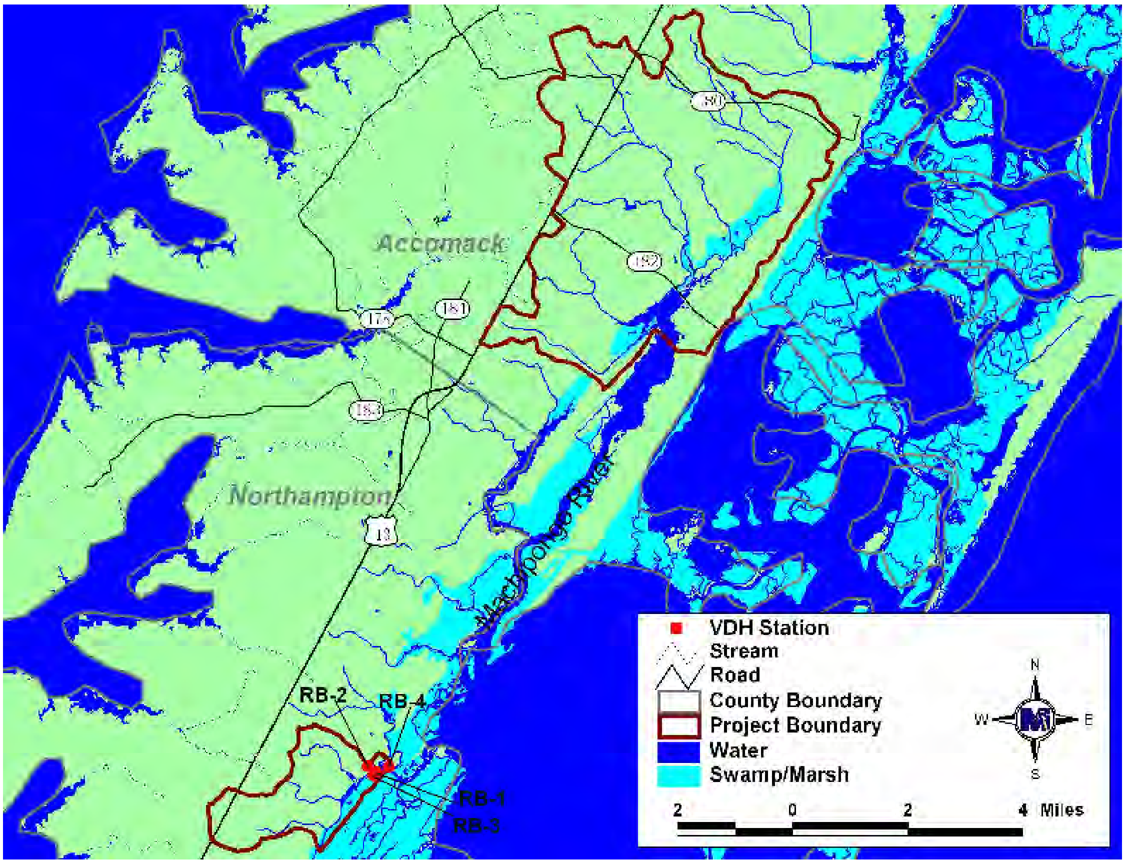

Figure 2.2 Location of VDH water quality monitoring stations in the Red Bank Creek and Machipongo River watersheds.

Table 2.1 Summary of *enterococci* (cfu/100mL) data collected by VADEQ from September 2001 – December 2006.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Red Bank Creek	7-RBC002.06	8/05 - 8/06	9	25	2,000	561	75	853	33.3%
Machipongo River	7-MAC008.55	9/01 - 12/06	9	25	1,600	163	25	410	22.2%

[1] Based on the instantaneous *enterococci* standard of 104 cfu/100mL.

Table 2.2 Summary of fecal coliform (cfu/100mL) data collected by the VDH from January 2000 – July 2012.

Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation
RB1	1/00 - 7/12	119	1	1,200	35	4	159
RB2	1/00 - 7/12	119	1	1,200	32	7	120
RB3	1/00 - 7/12	119	1	1,200	48	7	165
RB4	1/00 - 7/12	119	0	1,100	12	1	101
1	1/00 - 7/12	138	0	43	3	3	4
1_5	1/00 - 7/12	138	0	1,200	26	1	140
2	1/00 - 7/12	138	0	75	4	3	8
3	1/00 - 7/12	138	0	460	8	3	41
3_5	1/00 - 7/12	138	0	14	1	0	2
4	1/00 - 7/12	138	0	1,100	12	3	93
5	1/00 - 7/12	138	0	240	7	3	23
6	1/00 - 7/12	138	0	460	12	3	56
6M	1/00 - 7/12	138	0	460	22	4	69
6P	1/00 - 7/12	138	0	1,100	22	4	108
6R	1/00 - 7/12	138	0	460	14	3	49
6S	1/00 - 7/12	138	0	1,100	16	3	95
6T	1/00 - 7/12	138	0	1,100	24	3	110
6U	1/00 - 7/12	138	0	460	14	3	59
6V	1/00 - 7/12	138	0	460	14	3	50

Table 2.2 Summary of fecal coliform (cfu/100mL) data collected by the VDH from January 2000 – July 2012 (cont.).

Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation
6W	1/00 - 7/12	138	0	240	9	3	25
6X	1/00 - 7/12	138	0	75	6	3	10
6Y	1/00 - 7/12	138	0	43	5	3	7
6Z	1/00 - 7/12	138	0	43	4	3	6
7	1/00 - 7/12	138	0	23	4	3	4
8	1/00 - 7/12	138	0	460	8	3	40
9	1/00 - 7/12	138	0	23	4	3	5
10	1/00 - 7/12	138	0	43	4	3	6
11	1/00 - 7/12	138	0	460	8	3	40
12	1/00 - 7/12	138	0	1,200	17	3	103
13	1/00 - 7/12	138	0	1,200	16	3	102
14	1/00 - 7/12	138	0	1,200	17	3	104
15	1/00 - 7/12	138	0	1,200	27	3	140
21	1/00 - 7/12	138	0	93	2	0	8
23	1/00 - 7/12	138	0	23	2	1	3
25	1/00 - 7/12	138	0	1,100	10	1	94
27U	1/00 - 7/12	138	0	460	8	1	42
27V	1/00 - 7/12	138	0	93	4	1	12
27W	1/00 - 7/12	138	0	1,200	11	1	102
27X	1/00 - 7/12	138	0	150	3	1	13
27Y	1/00 - 7/12	138	0	150	3	1	13
27Z	1/00 - 7/12	138	0	150	3	1	13
28	1/00 - 7/12	138	0	1,100	10	1	94
31	1/00 - 7/12	138	0	9	1	0	2
33	1/00 - 7/12	138	0	23	2	1	3
36	1/00 - 7/12	138	0	9	1	1	2

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3. BACTERIA SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal bacteria in the Red Bank Creek and Machipongo River watersheds study area. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in **Appendix C**.

3.1. Assessment of Permitted Sources

There are no point sources permitted to discharge to surface water bodies in the Red Bank Creek and Machipongo River watersheds study area through the Virginia Pollutant Discharge Elimination System (VPDES).

There is one Animal Feeding Operation (AFOs) facility in the study area (VPG250063). Most of the poultry litter from this facility is land-applied outside of the watershed. The amount applied within the watershed was taken into account.

3.2. Assessment of VDH-DSS Shellfish Condemnation Sources

The VDH-DSS has performed sanitary shoreline surveys for each of the watersheds. The economy of the Red Bank Creek condemnation area is primarily dependent upon agriculture while that of the Machipongo River condemnation is dependent upon seafood as well. Both watersheds contained on-site sewage deficiencies with a much larger number in the Machipongo River condemnation. Both had dwellings and boating marinas posing pollution potential. One of the dump sites in the Machipongo River area posed a direct impact on shellfish waters. Livestock in both watersheds, including a poultry operation in the Machipongo River watershed, pose both direct and indirect impacts on shellfish waters.

3.3. Assessment of Nonpoint Sources

In the Red Bank Creek and Machipongo River watersheds study area, both residential and agricultural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, land application of waste (livestock), livestock, wildlife, and pets. Sources were identified and enumerated. MapTech previously collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria. This analysis was used to support the modeling process for the current project. Where appropriate, the spatial distribution of sources was also determined.

3.3.1. Private Residential Sewage Treatment

Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (**Table 3.1**). In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category “Other Means” includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage via a straight pipe (direct stream outfall).

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity or the capacity is reduced by a blockage, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal bacteria is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal bacteria to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors, previously performed by MapTech, showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech previously sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (MapTech, 2001). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.1 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for areas contributing to impaired segments in the Red Bank Creek and Machipongo River watersheds study area.

Impairment	Human Population	Housing Units	Homes with Sanitary Sewer	Homes with Septic Systems	Estimated Homes with Failing Septics	Estimated Homes with Straight Pipes
Red Bank Creek	240	127	0	125	4	0
Machipongo River	1,335	700	0	673	22	28
Total	**1,575**	**827**	**0**	**798**	**26**	**28**

3.3.2. Biosolids

Biosolids have not been applied in the Red Bank Creek and Machipongo River watersheds study area.

3.3.3. Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Red Bank Creek and Machipongo River watersheds study area watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured by MapTech. Fecal coliform density for dogs and cats was previously measured from samples collected by MapTech. A summary of the data collected is given in **Table 3.2**.

Table 3.3 lists the domestic animal populations for impairments in the Red Bank Creek and Machipongo River watersheds study area.

Table 3.2 Domestic animal population density, waste load, and fecal coliform (FC) density.

Variable	Dog	Cat
Population Density (animal/house)*	0.534	0.598
Waste load (g/animal-day)**	450	19.4
FC Density (cfu/g)	480,000	9

* animals per house
** grams per animal per day

Table 3.3 Estimated domestic animal populations in areas contributing to impaired segments in the Red Bank Creek and Machipongo River watersheds study area.

Impairment	Dogs	Cats
Red Bank Creek	55	61
Machipongo River	324	362
Total	**379**	**423**

3.3.4. Livestock

The predominant type of livestock in the Red Bank Creek and Machipongo River watersheds study area is poultry. Although poultry litter is spread on several fields in the Machipongo River watershed, the majority is applied to fields outside the study area. Other types of livestock identified were also considered in modeling the watershed. **Table 3.4** gives a summary of livestock populations in the Red Bank Creek and Machipongo River watersheds study area. Animal populations were based on communication with VADEQ, Eastern Shore Soil and Water Conservation District (ESSWCD), watershed visits, and verbal communication with citizens at the first public meeting.

Table 3.4 Livestock populations in areas contributing to impaired segments in the Red Bank Creek and Machipongo River watersheds study area.

Impairment	Beef	Sheep	Chicken	Horse
Red Bank Creek	8	3	0	5
Machipongo River	0	21	63,000	5
Total	**8**	**24**	**63,000**	**10**

Values of fecal coliform density of livestock sources were based on sampling previously performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in **Table 3.5**.

Table 3.5 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/animal)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off Factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA
Poultry (4 lb)	0.17	586,000	0.5

[1]units are cfu/100ml

Fecal bacteria produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.*, pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. **Table 3.6** shows the average percentage of collected livestock waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities may have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.6 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total Beef	Land use
January	4.00	Cropland
February	4.00	Cropland
March	12.00	Cropland
April	12.00	Cropland
May	12.00	Cropland
June	8.00	Pasture
July	8.00	Pasture
August	8.00	Pasture
September	12.00	Cropland
October	12.00	Cropland
November	4.00	Cropland
December	4.00	Cropland

Some livestock were expected to deposit a portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was estimated based on projects in other areas of Virginia. Horses and sheep were assumed to be in pasture 100% of the time.

It was assumed that beef cattle were expected to make a significant contribution through direct deposition with access to flowing water. For areas where direct deposition by cattle is assumed, the average amount of time spent by dairy and beef cattle in stream access areas for each month is given in **Table 3.7** and **Table 3.8**.

Table 3.7 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.3	0.7	0
February	23.3	0.7	0
March	22.6	1.4	0
April	21.8	2.2	0
May	21.8	2.2	0
June	21.1	2.9	0
July	21.1	2.9	0
August	21.1	2.9	0
September	21.8	2.2	0
October	22.6	1.4	0
November	22.6	1.4	0
December	23.3	0.7	0

Table 3.8 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.5. Wildlife

The predominant wildlife species in the Red Bank Creek and Machipongo River watersheds study area were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, and source sampling. Population densities were calculated from data provided by VDGIF and FWS, and are listed in **Table 3.9** (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987).

Table 3.9 Wildlife population densities for the Red Bank Creek and Machipongo River watersheds study area.

Deer (animal/ac of habitat)	Turkey (an/ac of habitat)	Raccoon (an/ac of habitat)	Muskrat (an/ac of habitat)	Beaver (an/mi of stream)	Duck (an/ac of habitat)	Goose (an/ac of habitat)
0.1032	0.0114	0.0703	0.3128	0.2500	0.0652	0.0320

The numbers of animals estimated to be in the Red Bank Creek and Machipongo River watersheds study area are reported in **Table 3.10**. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999b).

Table 3.10 Estimated wildlife populations in the Red Bank Creek and Machipongo River watersheds study area.

Impairment	Deer	Turkey	Raccoon	Muskrat	Beaver	Duck	Goose
Red Bank Creek	216	20	148	152	33	32	16
Machipongo River	1,425	161	970	827	82	172	85
Total	**1,641**	**181**	**1,118**	**979**	**115**	**204**	**101**

Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in **Table 3.11**.

Table 3.11 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Deer	380,000	5
Turkey	1,332	5
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Duck	3,500	75
Goose	250,000	50

Table 3.12 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech.

Table 3.12 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	**Primary** = region within 600 ft of perennial streams **Secondary** = region between 601 and 7,920 ft from perennial streams **Infrequent/Seldom** = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Beaver[1]	200	**Primary** = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) **Infrequent/Seldom** = rest of the watershed area
Deer	772	**Primary** = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land **Secondary** = low density residential, medium density residential **Infrequent/Seldom** = remaining land use areas
Turkey[2]	320	**Primary** = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land **Secondary** = cropland, pasture **Infrequent/Seldom** = remaining land use areas
Goose[3]	225	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Mallard (Duck)	150	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area

[1] Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2] Waste load for domestic turkey (ASAE, 1998).
[3] Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003)

4. BACTERIA MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

This chapter represents a brief description of the modeling procedures. The complete description is presented in **Appendix B**. Computer modeling is used in this study as a tool that allows simulating the interaction between the land surface and subsurface and the quantities of various bacteria sources by location. The model allows the climatological factors and in particular, precipitation, to drive this interaction. By modeling the watershed conditions and bacteria sources, the model allows quantifying the relationship between sources as they exist throughout the watershed to bacteria concentrations within the watershed. Two modeling approaches were used in the analysis. For the free flowing tributaries, the model used was the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources.

For the tidal Red Bank Creek-Machipongo River segments, the Steady State Tidal Prism Model, which is used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model the tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. The majority of Red Bank Creek within the study area is tidally influenced as is the Machipongo River.

To adequately represent the spatial variation in the watershed parameters and pollutant quantification, the drainage area was divided into nine (9) sub watersheds (**Figure B. 1**). Hydrologic parameters collected for the watershed were adjusted based on previously conducted hydrologic calibration in nearby projects where flow was calibrated by comparing model output to observed flow.

Once the flow component was built, quantified bacteria sources were entered into the model and a simulated bacteria concentration was generated. The simulated bacteria concentration was calibrated by comparing model simulations of bacteria to observed bacteria values collected by VADEQ at multiple locations. Finally the bacteria concentration was validated using a different time period from the calibration period.

Existing conditions of bacteria were then entered into the model to simulate the baseline conditions. This stage gives an indication of the current, predicted, violation rates of the water quality standard. The model was then used in the allocations process where reductions are simulated for various sources until the bacteria standard was met. A complete description of the modeling approach is presented in **Appendix B**.

5. BACTERIAL ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For these impairments, the TMDLs are expressed in terms of colony forming units (or resulting concentration).

Allocation scenarios were modeled using HSPF. The first change made to existing conditions was adjusting the flood tides (incoming) so that the bacteria from the tides alone did not result in water quality standards violations. More scenarios were created by reducing direct and land-based bacteria until the water quality standards were attained. The TMDLs developed for the impairments in the Red Bank Creek and Machipongo River watersheds were based on three different Virginia State standards (*E. coli, enterococci*, and fecal coliform). As detailed in **section 2.2**, the DEQ riverine primary contact recreational use *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml. The DEQ estuarine primary contact recreational use *enterococci* standards state that the calendar month geometric-mean concentration shall not exceed 35 cfu/100 ml, and that a maximum single sample concentration of *enterococci* shall not exceed 104 cfu/100 ml. The VDH shellfishing use fecal coliform standards state that the 30-month geometric-mean concentration shall not exceed 14 MPN, and that the 30-month, 90^{th} percentile concentration of fecal coliform shall not exceed 49 MPN.

According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling bacteria with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* and *enterococci* through the use of the following equations (developed from a data set containing 493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc}) \qquad \textit{E. coli}$$

$$\log_2(C_{ent}) = 1.2375 + 0.59984 \cdot \log_2(C_{fc}) \qquad \textit{Enterococci}$$

where C_{ec} is the concentration of *E. coli* in cfu/100 mL, C_{ent} is the concentration of *enterococci* in cfu/100 mL and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period and pollutant loads were adjusted until the standards were met. The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the applicable water quality standards.

5.1. Margin of Safety (MOS)

In order to account for uncertainty in modeled output, a Margin of Safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of bacteria TMDLs is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of these TMDLs. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of these TMDLs are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration, and
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed.

- Modeling all outflow from straight pipes and failing septic systems at the human waste concentration including the gray-water portion.

5.2. Waste Load Allocations (WLAs)

There are no VPDES point sources currently permitted to discharge into the study area. The allocation for discharges is equivalent to current permit levels (design discharge and 126 cfu/100 mL). Future growth was accounted for by setting aside 1% of the TMDL for the creation of new permitted discharges.

5.3. Load Allocations (LAs)

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (livestock, wildlife, and straight pipes). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads most significantly impact bacteria concentrations during high-flow conditions, while direct deposition NPS most significantly impact low flow bacteria concentrations. When necessary, nonpoint source load reductions are performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs are implemented by land use. Reductions to direct nonpoint sources were performed by source. **Section 3** contains tables with the breakdown of the annual fecal coliform per animal per land use for contributing subwatersheds to each impairment.

5.4. Final Total Maximum Daily Loads (TMDLs)

Allocation scenarios were run until all impairments were allocated to 0% exceedances of all applicable standards. The first table in each of the following five sections represents the scenarios developed to determine the TMDLs. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, a scenario reflects the impact of eliminating direct human sources from straight pipes leading to the final allocation scenario that contains the predicted reductions needed to meet 0% exceedance of all applicable water quality standards. The graphs in the following sections depict the existing and allocated 30-day geometric mean in-stream bacteria concentrations.

The second table in each of the following sections shows the existing and allocated *E. coli* loads that are output from the HSPF model. The third table shows the final annual in-stream allocated loads for the appropriate bacteria species. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The final table is an estimation of the in-stream daily load of bacteria.

5.4.1. Red Bank Creek VADEQ Riverine Primary Contact Recreational Use Impairment (NTU 65.1)

Table 5.1 shows the allocation scenarios used to determine the final TMDL for the Red Bank Creek study area riverine recreational use impairment (VAT-D04R_RBC01A04). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100 mL). The existing condition, Scenario 1, shows violations of the geometric mean standard. Scenario 7 eliminates 40% or more of the inputs and meets the geometric mean standard of 126 cfu/100 mL. Although the riverine recreational use standard was met in Scenario 6, reductions were more severe than necessary to meet the standard. Consequently, Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.1 Allocation scenarios for reducing current *E. coli* bacteria loads in the riverine recreational use impairment of the Red Bank Creek study area (NTU 65.1).

Scenario	Percent Reductions to Existing Bacterial Loads							
	Wildlife Direct	**Wildlife Land Based**	**Livestock Direct**	**Livestock Land Based**	**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *E. coli* Standard percent violations**
		Barren[1], Forest, Wetland		**Pasture, LAX[2]**	**Cropland**	**Straight Pipes**	**Developed, Commercial**	**% >126 GM**
1	0	0	0	0	0	0	0	2.05
2	0	0	0	0	0	100	0	2.05
3	0	0	100	0	0	100	0	2.05
4	0	0	90	50	50	100	50	2.05
5	0	0	100	100	100	100	100	2.05
6	99	99	100	100	100	100	100	0.00
7[3]	99	99	43	45	40	100	40	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] Final TMDL Scenario.

Figure 5.1 show the existing and allocated monthly geometric mean *E. coli* concentrations, from the Red Bank Creek study area at the main watershed outlet (subwatershed 7) for the impaired riverine segment. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

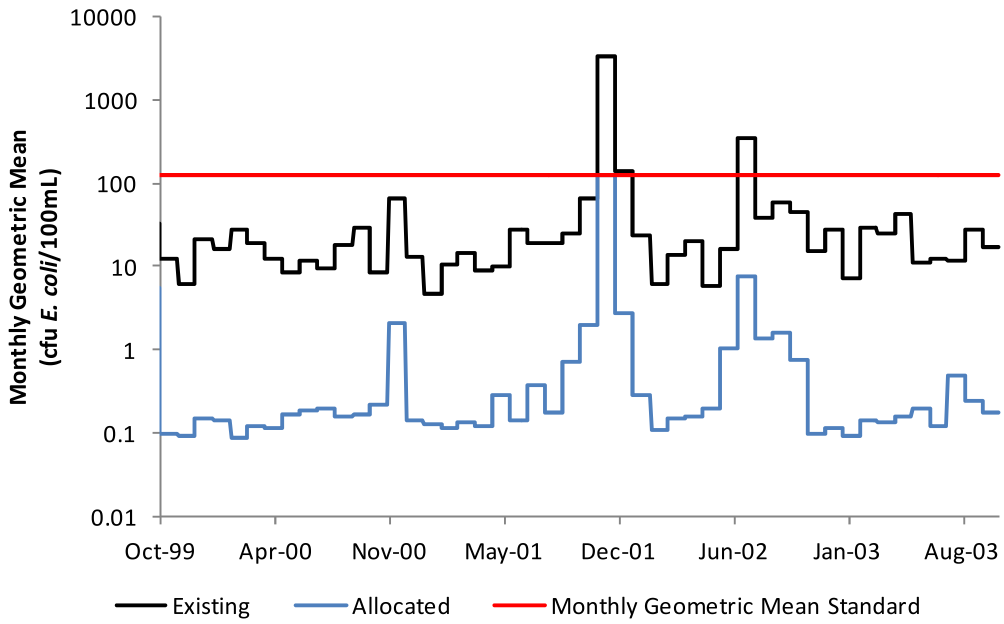

Figure 5.1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 7, Red Bank Creek NTU 65.1.

Table 5.2 contains estimates of existing and allocated in-stream *E. coli* loads for the Red Bank Creek area reported as annual cfu per year. The estimates are generated from available data, and these values are specific to the main outlet for the allocation rainfall and current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126 cfu/100 mL geometric mean standards are given in the final column.

Table C. 1 and **Table C. 3** in **Appendix C** include the land-based fecal coliform load distributions in the riverine reaches and offer more details for specific implementation development and source assessment evaluation.

Table 5.2 Estimated annual existing and allocated *E. coli* in-stream loads in the Red Bank Creek (NTU 65.1) study area impairments.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren*	1.31E+01	1.30E+01	99
	Developed	5.73E+09	2.29E+09	40
	Commercial	2.39E+08	9.55E+07	40
	Cropland	7.22E+09	2.89E+09	40
	Pasture	4.09E+09	1.84E+09	45
	Livestock Access	2.76E+08	1.24E+08	45
	Forest	5.49E+08	5.44E+08	99
	Wetland	1.77E+09	1.75E+09	99
Direct				
	Human	0.00E+00	0.00E+00	100
	Livestock	1.38E+09	5.92E+08	43
	Wildlife	7.01E+08	6.94E+08	99
Future Growth	Future Growth	0.00E+00	1.08E+08	N/A
Total Loads		**2.19E+10**	**1.09E+10**	**99.5****

* Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
** Calculations for total percent reductions are conducted excluding future growth.

Table 5.3 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.3 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Red Bank Creek (NTU 65.1) study area.

NTU	WLA[1]	LA	MOS	TMDL
Red Bank Creek Riverine Segment (NTU 65.1)	1.08E+08	1.08E+10	*Implicit*	1.09E+10
Future Load	1.08E+08			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily in-stream loads for the Red Bank Creek study area are shown in **Table 5.4.** The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.4 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Red Bank Creek (NTU 65.1) study area.

NTU	WLA[1]	LA	MOS	TMDL[2]
Red Bank Creek Riverine Segment (NTU 65.1)	2.96E+05	2.96E+07	*Implicit*	2.99E+07
Future Load	2.96E+05			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In **Table 5.3** and **Table 5.4**, the contribution from land-based sources (LA) in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.2. Red Bank Creek VADEQ VDH Shellfishing Use Impairment (NTU 65.1)

Table 5.5 shows allocation scenarios used to determine the final TMDL for Red Bank Creek (NTU 65.1) which contains the impairments on Red Bank Creek (VAT-D04E_RBC02A08, VAT-D04E_RBC03A08 and VAT-D04E_RBC01A08), including the Unnamed Tributary to Red Bank Creek (VAT-D04E_XDF01A04). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VDH fecal coliform shellfishing use standard. The existing condition, Scenario 1, shows violation of both standards without reductions. Scenario 6 meets the standards but contains reductions more severe than necessary. Scenario 7 eliminates sufficient inputs to meet the geometric mean standard of 14 cfu/100 mL and the 90^{th} percentile standard of 49 cfu/100 mL. This segment requires wildlife reductions of 84% and reductions from cropland, human, and pet sources. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.5 Allocation scenarios for reducing current bacteria loads in the shellfishing use impairments of Red Bank Creek (NTU 65.1).

Scenario	Percent Reductions to Existing Bacterial Loads							VADEQ Fecal Coliform Standard percent violations	
	Wildlife Direct	Wildlife Land Based	Livestock Direct	Livestock Land Based	Agricultural Land Based	Human Direct	Human and Pet Land Based		
		Barren[1], Forest, Wetland		Pasture, LAX[2]	Cropland	Straight Pipes	Developed, Commercial	% > 49 90%ile	% > 14 GM
1	0	0	0	0	0	0	0	100.00	100.00
2	0	0	0	0	0	100	0	100.00	100.00
3	0	0	100	0	0	100	0	100.00	100.00
4	0	0	90	50	50	100	50	100.00	93.89
5	0	0	100	100	100	100	100	100.00	39.44
6	84	84	100	100	100	100	100	0.00	0.00
7[3]	84	84	0	0	100	100	83	0.00	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] Final TMDL Scenario

Figure 5.2 shows the existing and allocated fecal coliform concentrations, at the main watershed outlet (subwatershed 3). The graph shows existing conditions in black, with allocated conditions overlaid in blue. Allocations are controlled by the shellfishing use 90th percentile standard and by existing fecal coliform concentrations in subwatershed 6.

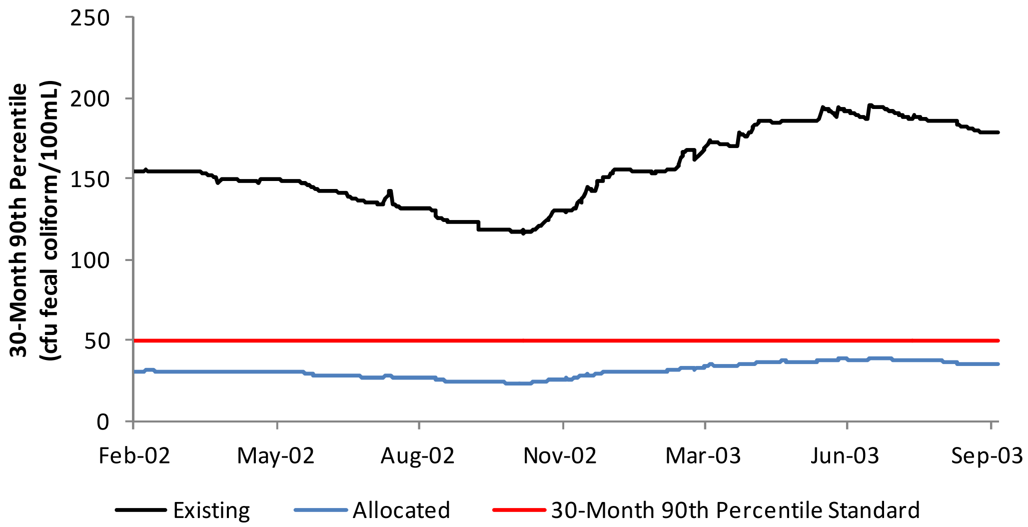

Figure 5.2 Existing and allocated monthly in-stream fecal coliform concentrations in subwatershed 3, outlet of NTU 65.1.

Table 5.6 contains estimates of existing and allocated in-stream fecal coliform loads for the Red Bank Creek area reported as annual cfu per year. The estimates are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 90th percentile standard of 49 cfu/100 mL are given in the final column.

Table C. 4 and **Table C. 6** in **Appendix C** include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.6 Estimated existing and allocated fecal coliform in-stream loads in the Red Bank Creek (NTU 65.1) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren*	1.53E+00	1.53E+00	84
	Developed	6.73E+12	1.14E+12	83
	Commercial	8.19E+07	2.47E+07	83
	Cropland	2.49E+12	1.49E+09	100**
	Pasture	8.85E+12	8.84E+12	0
	Livestock Access	5.76E+08	4.84E+07	0
	Forest	1.02E+13	1.63E+12	84
	Wetland	1.90E+14	3.05E+13	84
Direct				
	Human	0.00E+00	0.00E+00	100
	Livestock	0.00E+00	0.00E+00	0
	Wildlife	5.20E+11	8.32E+10	84
Future Growth	Future Growth	0.00E+00	5.10E+11	N/A
Total Loads		**2.19E+14**	**5.15E+13**	**99.8%*** **

***** Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
****** The 100% reduction applies within the tidal portion of Red Bank only. Thus some loading from upstream non-tidal areas is represented in the allocation run.
******* Calculations for total percent reductions are conducted excluding future growth.

Table 5.7 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.7 Final annual in-stream fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Red Bank Creek (NTU 65.1) study area.

NTU	WLA[1]	LA	MOS	TMDL
Red Bank Creek Estuarine Segments (NTU 65.1)	5.10E+11	5.10E+13	*Implicit*	5.15E+13
Future Load	5.10E+11			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Red Bank Creek (NTU 65.1) study area are shown in **Table 5.8**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 14 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.8 Final average daily in-stream fecal coliform bacterial loads (cfu/day) modeled after TMDL allocation in the Red Bank Creek study area impairments (NTU 65.1).

NTU	WLA[1]	LA	MOS	TMDL[2]
Red Bank Creek Estuarine Segments (NTU 65.1)	1.40E+09	1.40E+11	*Implicit*	1.41E+11
Future Load	1.40E+09			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 14 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In **Table 5.7** and **Table 5.8**, the contribution from land-based sources (LA) in these tables is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the two tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.3. Red Bank Creek VADEQ Estuarine Primary Contact Recreational Use Impairment (NTU 65.1)

Table 5.9 shows allocation scenarios used to determine the final TMDL for Red Bank Creek (NTU 65.1) which contains the impairments on Red Bank Creek (VAT-D04E_RBC02A08, VAT-D04E_RBC03A08, VAT-D04E_RBC04A08 and VAT-D04E_RBC01A08), and on an Unnamed Tributary to Red Bank Creek (VAT-D04E_XDF01A04). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ estuarine primary contact recreational use (swimming) 30-day geometric mean standard (35 cfu/100 mL geometric mean). The existing condition, Scenario 1, shows moderate violation of the geometric mean standard. Scenario 7 shows enough improvement to meet the geometric mean standard of 35 cfu/100 mL. This scenario requires wildlife reductions of 84%, and cropland, human, and pet reductions. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.9 Allocation scenarios for reducing current bacteria loads in the estuarine recreational use impairment of Red Bank Creek (NTU 65.1).

Scenario	Percent Reductions to Existing Bacterial Loads							
	Wildlife Direct	**Wildlife Land Based**	**Livestock Direct**	**Livestock Land Based**	**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *Enterococci* Standard percent violations**
		Barren[1], Forest, Wetland		**Pasture, LAX[2]**	**Cropland**	**Straight Pipes**	**Developed, Commercial**	**% >35 GM**
1	0	0	0	0	0	0	0	10.27
2	0	0	0	0	0	100	0	10.27
3	0	0	100	0	0	100	0	10.27
4	0	0	90	50	50	100	50	10.27
5	0	0	100	100	100	100	100	8.21
6	84	84	100	100	100	100	100	0.00
7[3]	84	84	0	0	100	100	83	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] Final TMDL Scenario

Figure 5.3 shows the existing and allocated monthly geometric mean *enterococci* concentrations, at the NTU outlet (subwatershed 3). The graph shows existing conditions in black, with allocated conditions overlaid in blue.

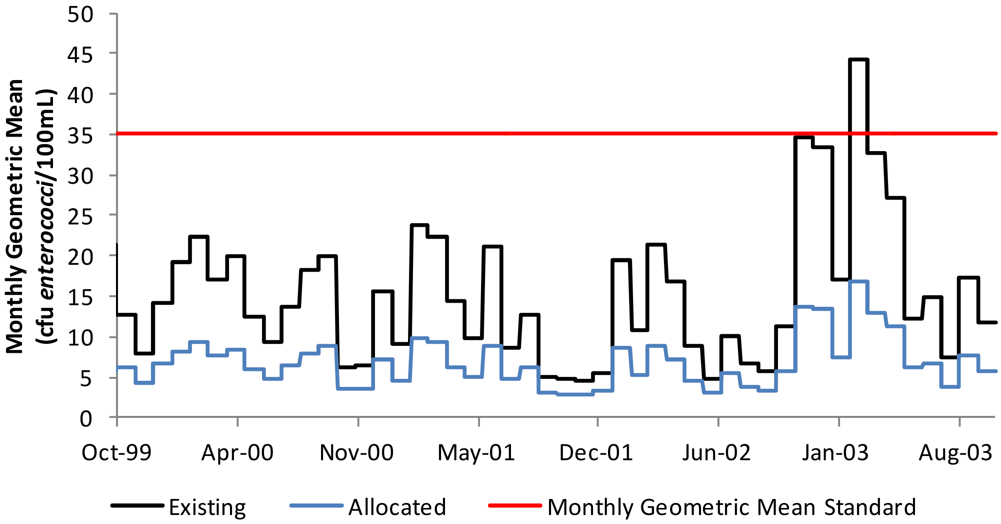

Figure 5.3 Existing and allocated monthly geometric mean in-stream *Enterococci* concentrations in the Red Bank Creek impairment, outlet subwatershed 3 of NTU 65.1.

Table 5.10 contains estimates of existing and allocated in-stream *enterococci* loads for the Red Bank Creek area (NTU 65.1) reported as annual cfu per year. The estimates in Table 5.6 are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 35 cfu/100 mL geometric mean standard are given in the final column.

Table C. 4 and **Table C. 6** in **Appendix C** include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.10 Estimated existing and allocated *Enterococci* in-stream loads in the Red Bank Creek (NTU 65.1) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren*	2.71E+00	2.28E+00	84
	Developed	3.62E+07	3.01E+07	83
	Commercial	5.78E+04	4.79E+04	83
	Cropland	5.62E+05	5.62E+05	100
	Pasture	1.03E+08	1.03E+08	0
	Livestock Access	7.18E+04	7.18E+04	0
	Forest	4.45E+07	3.74E+07	84
	Wetland	2.57E+08	2.16E+08	84
Direct				
	Human	0.00E+00	0.00E+00	100
	Livestock	0.00E+00	0.00E+00	0
	Wildlife	7.45E+06	6.26E+06	84
Future Growth	Future Growth	0.00E+00	3.93E+06	N/A
Total Loads		**4.49E+08**	**3.97E+08**	**99.1****

* Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
** Calculations for total percent reductions are conducted excluding future growth.

Table 5.11 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.11 Final annual in-stream *Enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Red Bank Creek (NTU 65.1) study area.

NTU	WLA[1]	LA	MOS	TMDL
Red Bank Creek Estuarine Segments (NTU 65.1)	3.93E+06	3.93E+08	*Implicit*	3.97E+08
Future Load	3.93E+06			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily in-stream loads for Red Bank Creek (NTU 65.1) study area are shown in **Table 5.12**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 104 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.12 Final average daily in-stream *Enterococci* loads (cfu/day) modeled after TMDL allocation in the Red Bank Creek impairment (NTU 65.1).

NTU	WLA[1]	LA	MOS	TMDL[2]
Red Bank Creek Estuarine Segments (NTU 65.1)	1.08E+04	1.08E+06	*Implicit*	1.09E+06
Future Load	1.08E+04			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 104 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In **Table 5.11** and **Table 5.12**, the contribution from land-based sources (LA) is subject to die-off. On the other hand, the WLA is calculated using a facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.4. Machipongo River VADEQ VDH Shellfishing Use Impairment (NTU 65.2)

Table 5.13 shows allocation scenarios used to determine the final TMDL for the Machipongo River (NTU 65.2) which contains the impairment on the Machipongo River (VAT-D04E_MAC01A00). Because Virginia's water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VDH fecal coliform shellfishing use standards. The existing condition, Scenario 1, shows violation of both standards. Scenario 7 eliminates 75% or more of the inputs from all source categories to meet the geometric mean standard of 14 cfu/100 mL and the 90th percentile standard of 49 cfu/100 mL. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.13 Allocation scenarios for reducing current bacteria loads in the shellfishing use impairment of Machipongo River (NTU 65.2).

Scenario	Percent Reductions to Existing Bacterial Loads									
	Wildlife Direct	**Wildlife Land Based**	**Livestock Direct**	**Livestock Land Based**		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ Fecal Coliform Standard percent violations**	
		Barren[1], Forest, Wetland		**Pasture**	**LAX[2]**	**Cropland**	Straight Pipes	**Developed, Commercial**	**% > 49 90th %ile**	**% > 14 GM**
1	0	0	0	0	0	0	0	0	100.00	16.36
2	0	0	0	0	0	0	100	0	93.40	10.27
3	0	0	100	0	0	0	100	0	93.40	10.27
4	0	0	90	50	50	50	100	50	55.12	10.27
5	0	0	100	100	100	100	100	100	0.00	8.21
6	79	79	100	100	100	100	100	100	0.00	0.00
7[3]	79	79	75	100	99	100	100	95	0.00	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] Final TMDL Scenario

Figure 5.4 shows the existing and allocated fecal coliform concentrations, at the main watershed outlet (subwatershed 1). The graph shows existing conditions in black, with allocated conditions overlaid in blue. The allocations in outlet segment 1 are limited by the high violation rate in subwatershed 2 of the 90th percentile standard.

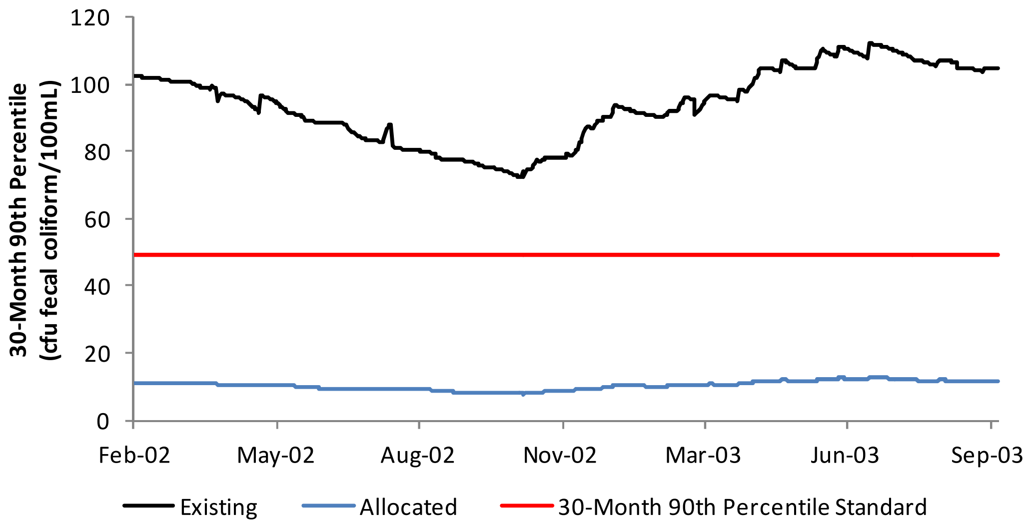

Figure 5.4 Existing and allocated monthly in-stream fecal coliform concentrations in subwatershed 1, outlet of NTU 65.2.

Table 5.14 contains estimates of existing and allocated in-stream fecal coliform loads for the Machipongo River area reported as annual cfu per year. The estimates in **Table 5.14** are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 90th percentile standard of 49 cfu/100 mL and the geometric mean standard of 14 cfu/100 mL are given in the final column.

Table C. 1 and **Table C. 2** in **Appendix C** include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.14 Estimated annual existing and allocated fecal coliform in-stream loads in the Machipongo River (NTU 65.2) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren*	1.16E+12	2.46E+11	79
	Developed	1.04E+14	5.37E+12	95
	Commercial	2.89E+12	1.44E+11	95
	Cropland	3.81E+14	0.00E+00	100
	Pasture	3.36E+14	0.00E+00	100
	Livestock Access	1.72E+11	1.73E+09	99
	Forest	2.37E+14	5.00E+13	79
	Wetland	6.59E+14	1.54E+14	79
Direct				
	Human	3.02E+13	0.00E+00	100
	Livestock	0.00E+00	0.00E+00	75
	Wildlife	3.79E+12	7.95E+11	79
Future Growth	Future Growth	0.00E+00	2.04E+12	N/A
Total Loads		**1.76E+15**	**2.06E+14**	**99.9****

* Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
** Calculations for total percent reductions are conducted excluding future growth.

Table 5.15 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.15 Final annual in-stream fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Machipongo River (NTU 65.2) study area.

NTU	WLA[1]	LA	MOS	TMDL
Machipongo River (NTU 65.2)	2.04E+12	2.04E+14	*Implicit*	2.06E+14
Future Load	2.04E+12			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Machipongo River (NTU 65.2) study area are shown in **Table 5.16**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 14 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.16 Final average daily in-stream fecal coliform bacterial loads (cfu/day) modeled after TMDL allocation in the Machipongo River study area impairments (NTU 65.2).

NTU	WLA[1]	LA	MOS	TMDL[2]
Machipongo River (NTU 65.2)	5.58E+09	5.58E+11	*Implicit*	5.64E+11
Future Load	5.58E+09			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 14 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In **Table 5.15** and **Table 5.16**, the contribution from land-based sources (LA) in these tables is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the two tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

5.4.5. Machipongo River VADEQ Estuarine Primary Contact Recreational Use Impairment (NTU 65.2)

Table 5.17 shows allocation scenarios used to determine the final TMDL for Machipongo River (NTU 65.2) which contains an impairment on the Machipongo River (VAT-D04E_MAC01A00). Because Virginia’s water quality standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ estuarine primary contact recreational use (swimming) 30-day geometric mean standard (35 cfu/100 mL geometric mean). The existing condition, Scenario 1, does not show violations of the geometric mean standard. However, because the shellfishing use standard is violated at existing conditions in these waters, reductions were made across all sources in Scenarios 2 through 7 to meet the shellfishing use standard. Scenario 7 eliminates 75% or more of the inputs and also meets the estuarine recreational use geometric mean standard of 35 cfu/100 mL. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.17 Allocation scenarios for reducing current bacteria loads in the estuarine recreational use impairment of Machipongo River (NTU 65.2).

Scenario	Percent Reductions to Existing Bacterial Loads								VADEQ *Enterococci* Standard percent violations
	Wildlife Direct	Wildlife Land Based	Livestock Direct	Livestock Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	
		Barren[1], Forest, Wetland		Pasture	LAX[2]	Cropland	Straight Pipes	Developed, Commercial	% >35 GM
1	0	0	0	0	0	0	0	0	0.00
2	0	0	0	0	0	0	100	0	0.00
3	0	0	100	0	0	0	100	0	0.00
4	0	0	90	50	50	50	100	50	0.00
5	0	0	100	100	100	100	100	100	0.00
6	79	79	100	100	100	100	100	100	0.00
7[3]	79	79	75	100	99	100	100	95	0.00

[1]Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2]LAX - livestock pasture access near flowing streams.
[3] Final TMDL Scenario

Figure 5.5 shows the existing and allocated monthly geometric mean *enterococci* concentrations, at the NTU outlet (subwatershed 1). The graph shows existing conditions in black, with allocated conditions overlaid in blue. The apparent over-allocation is produced by the reductions required in subwatershed 2 due to violations of the more stringent shellfishing use 90th percentile standard.

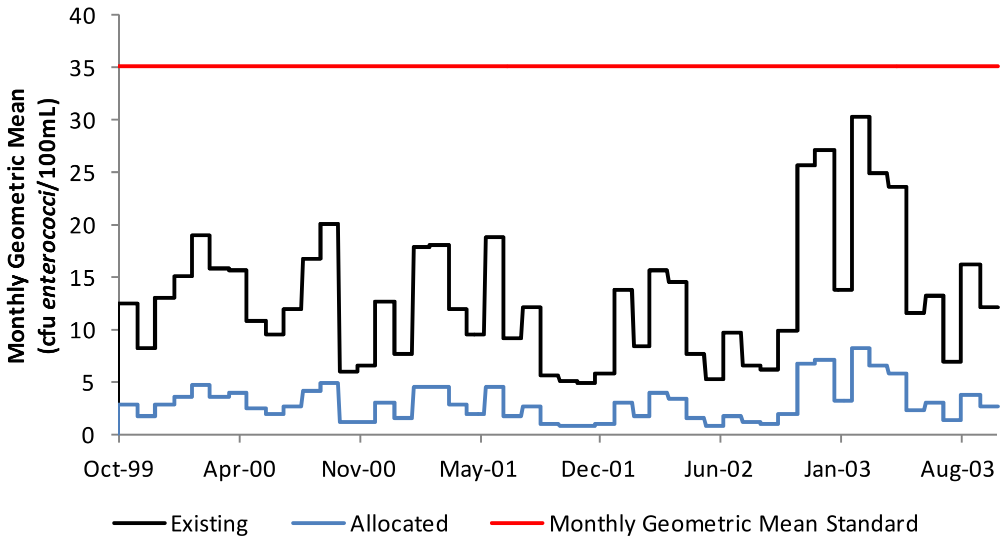

Figure 5.5 Existing and allocated monthly geometric mean in-stream *Enterococci* concentrations in the Machipongo River impairment, outlet subwatershed 1 of NTU 65.2.

Table 5.18 contains estimates of existing and allocated in-stream *enterococci* loads for the Machipongo River area (NTU 65.2) reported as annual cfu per year. The estimates are generated from available data, and these values are specific to the main outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 35 cfu/100 mL geometric mean standard are given in the final column.

Table C. 1 and **Table C. 2** in **Appendix C** include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.18 Estimated existing and allocated *Enterococci* in-stream loads in the Machipongo River (NTU 65.2) study area.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren*	1.33E+06	1.05E+06	79
	Developed	2.42E+07	2.30E+07	95
	Commercial	6.51E+05	6.19E+05	95
	Cropland	0.00E+00	0.00E+00	100
	Pasture	0.00E+00	0.00E+00	100
	Livestock Access	7.48E+03	7.40E+03	99
	Forest	2.71E+08	2.14E+08	79
	Wetland	8.37E+08	6.61E+08	79
Direct				
	Human	0.00E+00	0.00E+00	100
	Livestock	0.00E+00	0.00E+00	75
	Wildlife	4.31E+06	3.40E+06	79
Future Growth	Future Growth	0.00E+00	9.03E+06	N/A
Total Loads		**1.14E+09**	**9.12E+08**	**99.2****

* Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
** Calculations for total percent reductions are conducted excluding future growth.

Table 5.19 shows the annual TMDL, which gives the amount of bacteria that can be present in the stream in a given year, and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.19 Final annual in-stream *Enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Machipongo River (NTU 65.2) study area.

NTU	WLA[1]	LA	MOS	TMDL
Machipongo River (NTU 65.2)	9.03E+06	9.03E+08	*Implicit*	9.12E+08
Future Load	9.03E+06			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily in-stream loads for the Machipongo River (NTU 65.2) study area are shown in **Table 5.20**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 104 cfu/100 mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.20 Final average daily in-stream *Enterococci* loads (cfu/day) modeled after TMDL allocation in the Machipongo River impairment (NTU 65.2).

NTU	WLA[1]	LA	MOS	TMDL[2]
Machipongo River (NTU 65.2)	2.47E+04	2.47E+06	*Implicit*	2.50E+06
Future Load	2.47E+04			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 104 cfu/100 mL. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

In **Table** 5.19 through **Table 5.20**, the contribution from land-based sources (LA), as shown in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facilities are allowed to discharge into the river system before the load is subject to die-off.

6. IMPLEMENTATION

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. EPA requires that there is reasonable assurance that TMDLs can be implemented. TMDLs represent an attempt to quantify the pollutant load that might be present in a waterbody and still ensure attainment and maintenance of water quality standards. The Commonwealth intends to use existing programs in order to attain water quality goals.

The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1. Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on the VADEQ web site under www.deq.state.va.us/export/sites/default/tmdl/pdf/ppp.pdf.

6.2. Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. It enables tracking of water quality improvements following implementation through follow-up stream monitoring;

2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements;

4. It helps ensure that the most cost effective practices are implemented first; and

5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

6.3. Implementation of Waste Load Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

6.3.1. Stormwater

Prior to July 1, 2013, VADEQ and VADCR coordinated separate state permitting programs that regulated the management of pollutants carried by stormwater runoff. Since July 1, VADEQ regulates both stormwater discharges associated with industrial activities through its VPDES program, and stormwater discharges from construction sites and from municipal separate storm sewer systems (MS4s) through its VSMP program. As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented. More information regarding these programs can be found at http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx.

6.3.2. TMDL Modifications for New or Expanding Discharges

Permits issued for facilities with wasteload allocations developed as part of a Total Maximum Daily Load (TMDL) must be consistent with the assumptions and requirements of these wasteload allocations (WLA), as per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at www.deq.virginia.gov/waterguidance/.

6.4. Implementation of Load Allocations

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for non point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

6.4.1. Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003. It is available upon request from the VADEQ and VADCR TMDL project staff or at www.deq.virginia.gov/tmdl/implans/ipguide.pdf.

watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.4.2. Staged Implementation Scenarios

6.4.2.1. Bacteria

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Among the most efficient bacterial BMPs for both urban and rural watersheds are stream side fencing for cattle farms, pet waste clean-up programs, and government or grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes.

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

If water quality standards are not met upon implementation of all cost-effective and reasonable BMPs, a Use Attainability Analysis (UAA) may need to be initiated since Virginia's water quality standards allow for changes to use designations if existing water quality standards cannot be attained by implementing effluent limits required under §301b and §306 of Clean Water Act, and by implementing cost effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in **Section 6.6**.

Stage I scenarios are discussed in **Chapter 5**. Correcting 50% of straight pipes and sewer overflows will benefit the water quality significantly for all the impairments.

6.4.3. Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Red Bank Creek and Machipongo River watersheds.

6.4.4. Implementation Funding Sources

The implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), the Virginia

Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding source for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at www.deq.virginia.gov/bay/wqif.html and at www.dcr.virginia.gov/soil_&_water/wqia.shtml.

6.5. Follow-Up Monitoring

Because elements of this TMDL project (bacteria impairment) are being developed using a phased approach, monitoring to support refinement of these aspects of the TMDL is required. However, follow-up monitoring is also performed during implementation of standard (non-phased) TMDLs. Monitoring to support refinement of the phased TMDLs will begin as soon as is feasible upon approval of the TMDLs, and will likely require a more intensive monitoring effort than that which is described below for non-phased TMDLs.

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004 (www.deq.virginia.gov/waterguidance/pdf/032004.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The details of the follow-up ambient monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office.

The objective of the Statewide Fish Tissue and Sediment Monitoring Program is to systematically assess and evaluate, using a multi-tier screening, waterbodies in Virginia in order to identify toxic contaminant(s) accumulation with the potential to adversely affect human users of the resource. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

VADEQ staff, in cooperation with the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plans. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or to monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on VADEQ's citizen monitoring in Virginia and QA/QC guidelines is available at www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years.

6.6. Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use.

In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;

2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;

3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;

4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;

5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or

6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the EPA, will be able to provide comment. Additional information can be obtained at www.deq.virginia.gov/wqs/designated.html.

The process to address potentially unattainable reductions based on the above is as follows:

As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation is that all controllable sources would be reduced to the maximum extent possible using the implementation approaches described above. VADEQ will continue to monitor water quality in the stream during and subsequent to the implementation of these measures to determine if the water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E. provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a use attainability analysis according to the criteria listed above and a schedule established by the Board. The amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed".

7. PUBLIC PARTICIPATION

Public participation during TMDL development for the Red Bank Creek and Machipongo River watersheds was encouraged; a summary of the meetings is presented in **Table 7.1**. The first public meeting took place on December 13, 2012 at the Northampton Free Library in Nassawadox, Virginia. Four people attended the meeting. The second public meeting was held on August 15, 2013 and 5 people attended. The meetings were publicized by placing notices in the Virginia Register, and emailing notices to local stakeholders and representatives.

Table 7.1 Public participation during TMDL development for the upper Chickahominy River watershed.

Date	Location	Attendance[1]	Type
12/13/2012	Northampton Free Library Nassawadox, VA	4	1st public
8/15/2013	Northampton Free Library Nassawadox, VA	5	2nd public

[1] The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of stakeholders' committees, with committee and public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. Stakeholder committees will have the express purpose of formulating the TMDL Implementation Plan. The committees will consist of, but not be limited to, representatives from VADEQ and local governments. These committees will have the responsibility for identifying corrective actions that are founded in practicality, establishing a timeline to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota.

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Cause. 1. That which produces an effect (a general definition).

2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition).[2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition*. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* ***Respiration.***

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

DSS. Virginia Department of Health, Division of Shellfish Sanitation.

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle*. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology*. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated* *into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metric ton (Mg or t). A unit of mass equivalent to 1,000 kilograms. An annual load of a pollutant is typically reported in metric tons per year (t/yr).

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Most Probable Stressor(s): The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

Narrative criteria*. Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Non-Stressor(s): Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

Numeric targets*. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff*. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Polycyclic aromatic hydrocarbons (**PAH**s) are chemical compounds that consist of fused aromatic rings and do not contain heteroatoms or carry substituents. PAHs occur in oil, coal, and tar deposits, and are produced as byproducts of fuel burning (whether fossil fuel or biomass). As a pollutant, they are of concern because some compounds have been identified as carcinogenic, mutagenic, and teratogenic.

Possible Stressor(s): Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period*. The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity*. Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration*. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone*. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively* *narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

***Roughness coefficient**. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

***Runoff.** That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquatic systems as a result of erosion.

***Septic system**. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

***Sewer.** A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

***Simulation**. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

***Slope.** The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

***Spatial segmentation**. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff*. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area*. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water*. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards*. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Ton (T). A unit of measure of mass equivalent to 2,200 English lbs.

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under* *investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality*. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

APPENDIX A

Frequency Analysis of Bacteria Data

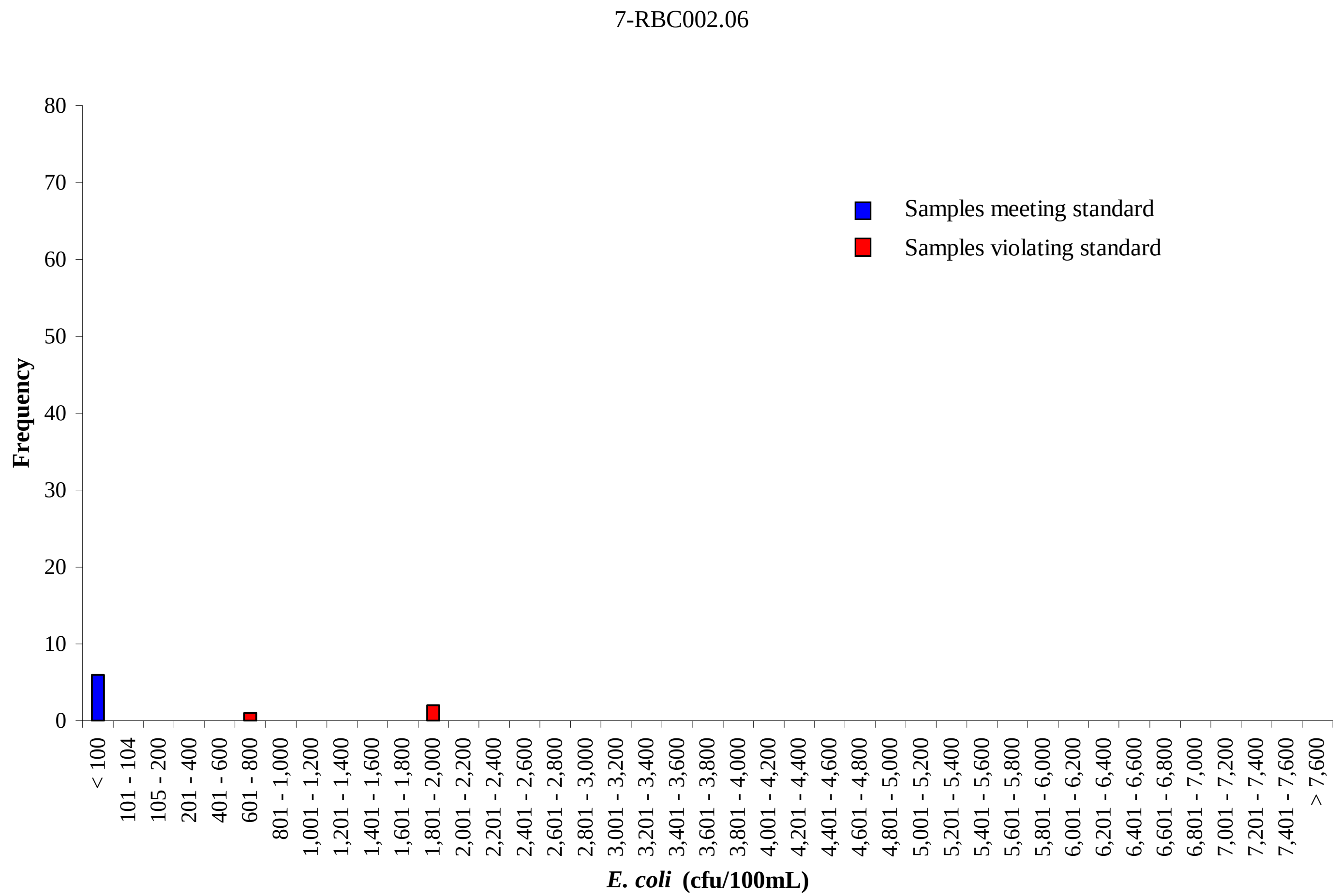

Figure A. 1 Frequency analysis of *Enterococci* concentrations at station 7-RBC002.06 in Red Bank Creek for the period from August 2005 to December 2006. VADEQ monitoring station.

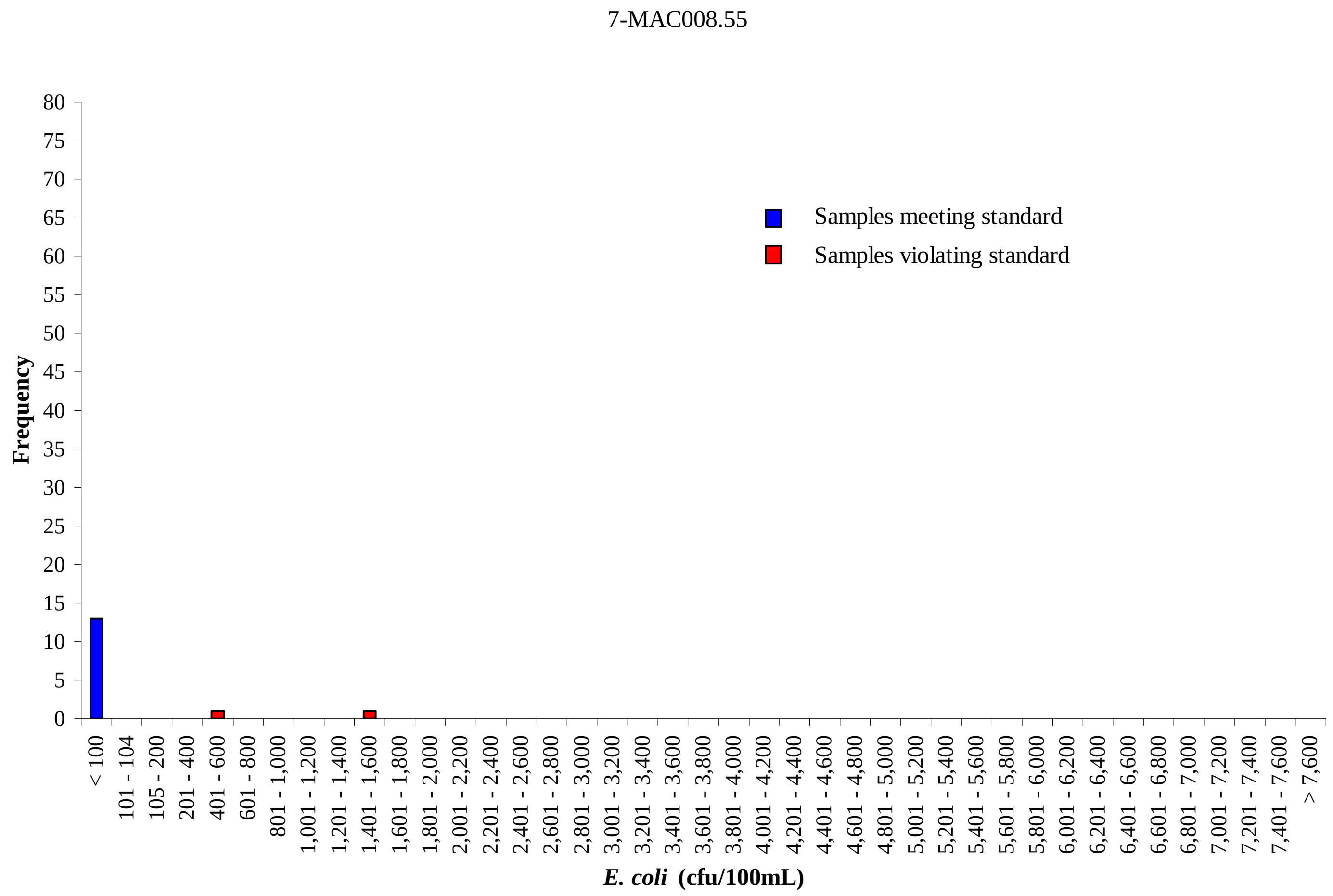

Figure A. 2 Frequency analysis of *Enterococci* concentrations at station 7-MAC008.55 in Machipongo River for the period from July 2004 to December 2006. VADEQ monitoring station.

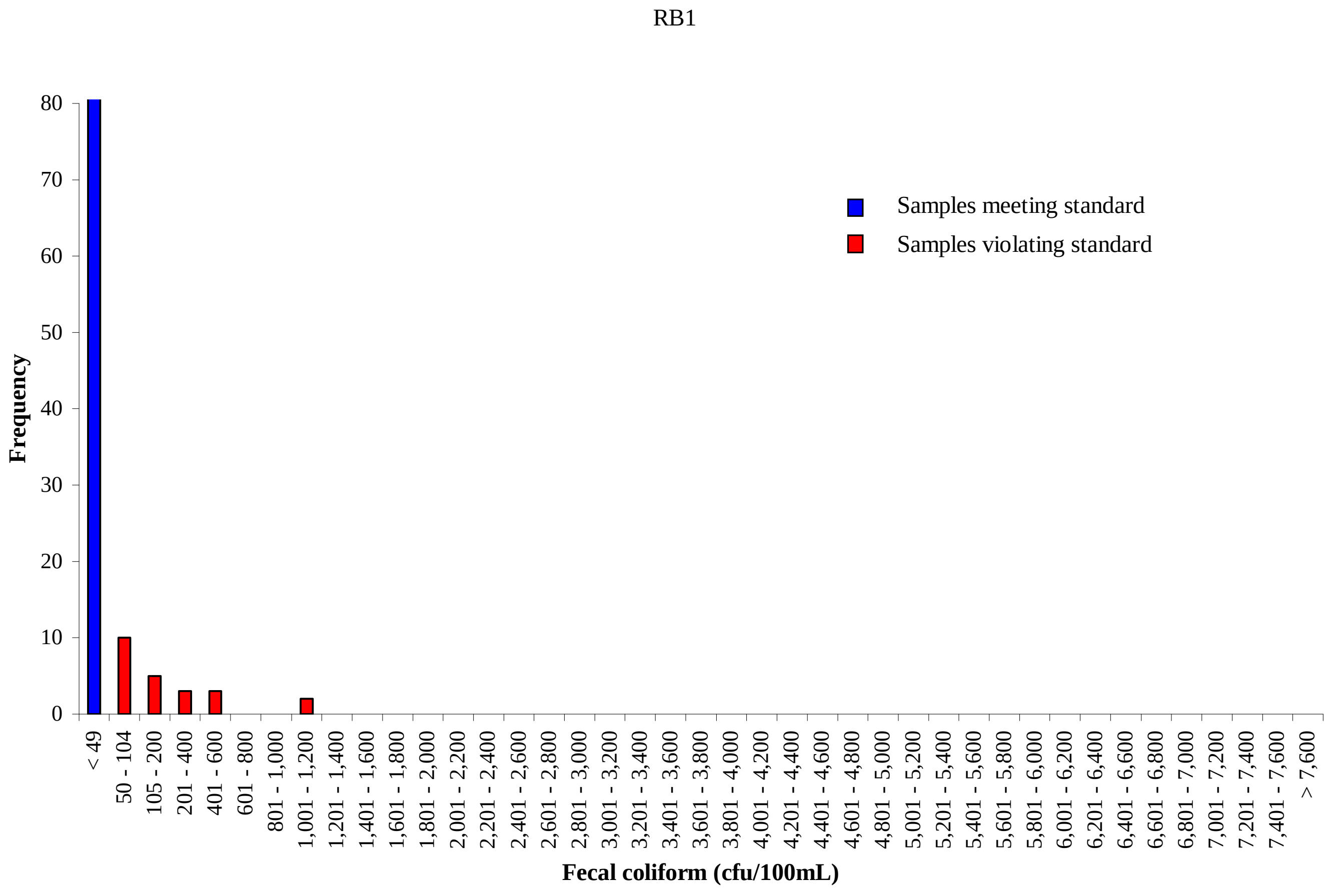

Figure A. 3 Frequency analysis of fecal coliform concentrations at station RB1 in Red Bank Creek for the period from February 1992 to July 2012. DSS monitoring station.

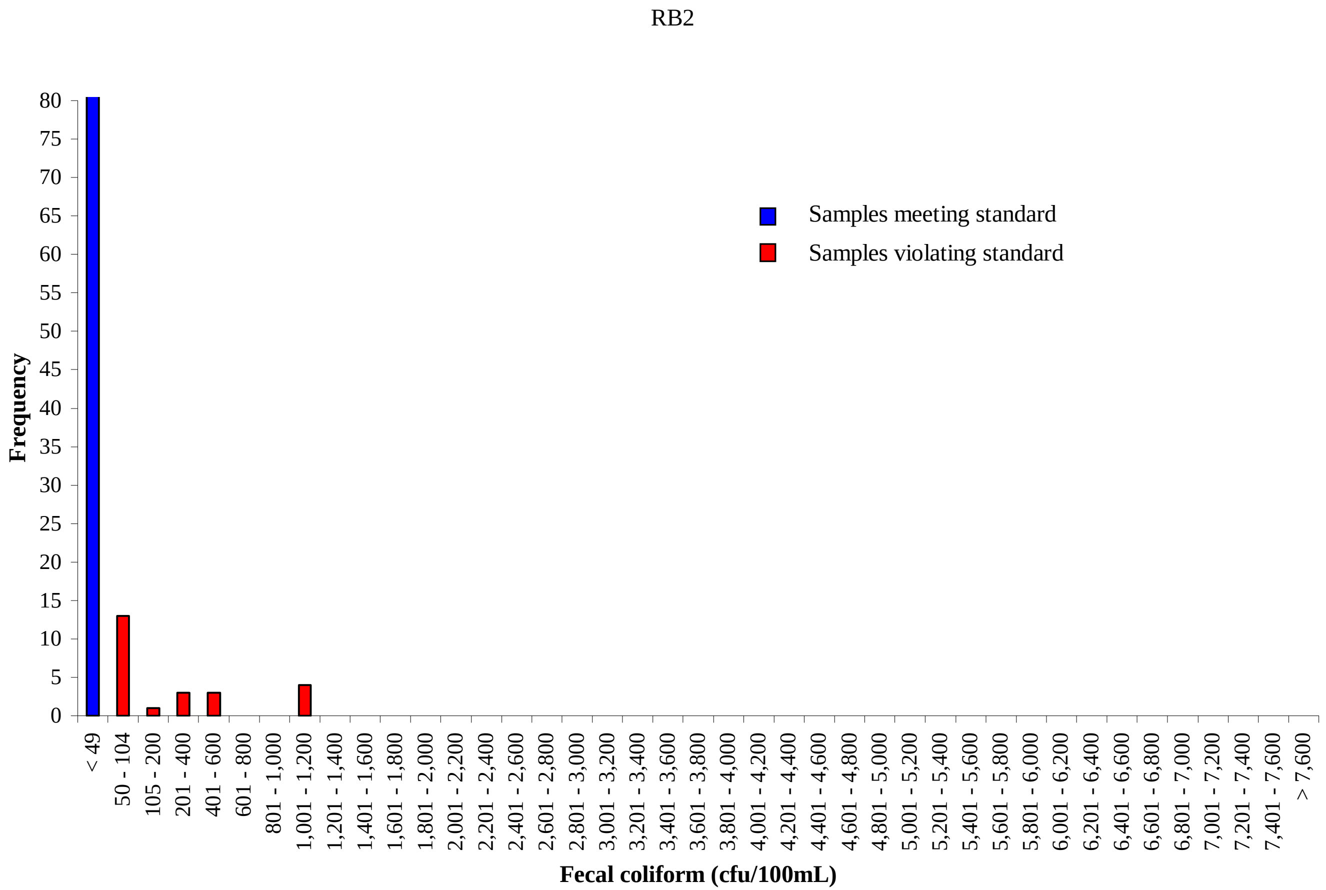

Figure A. 4 Frequency analysis of fecal coliform concentrations at station RB2 in Red Bank Creek for the period from February 1992 to July 2012. DSS monitoring station.

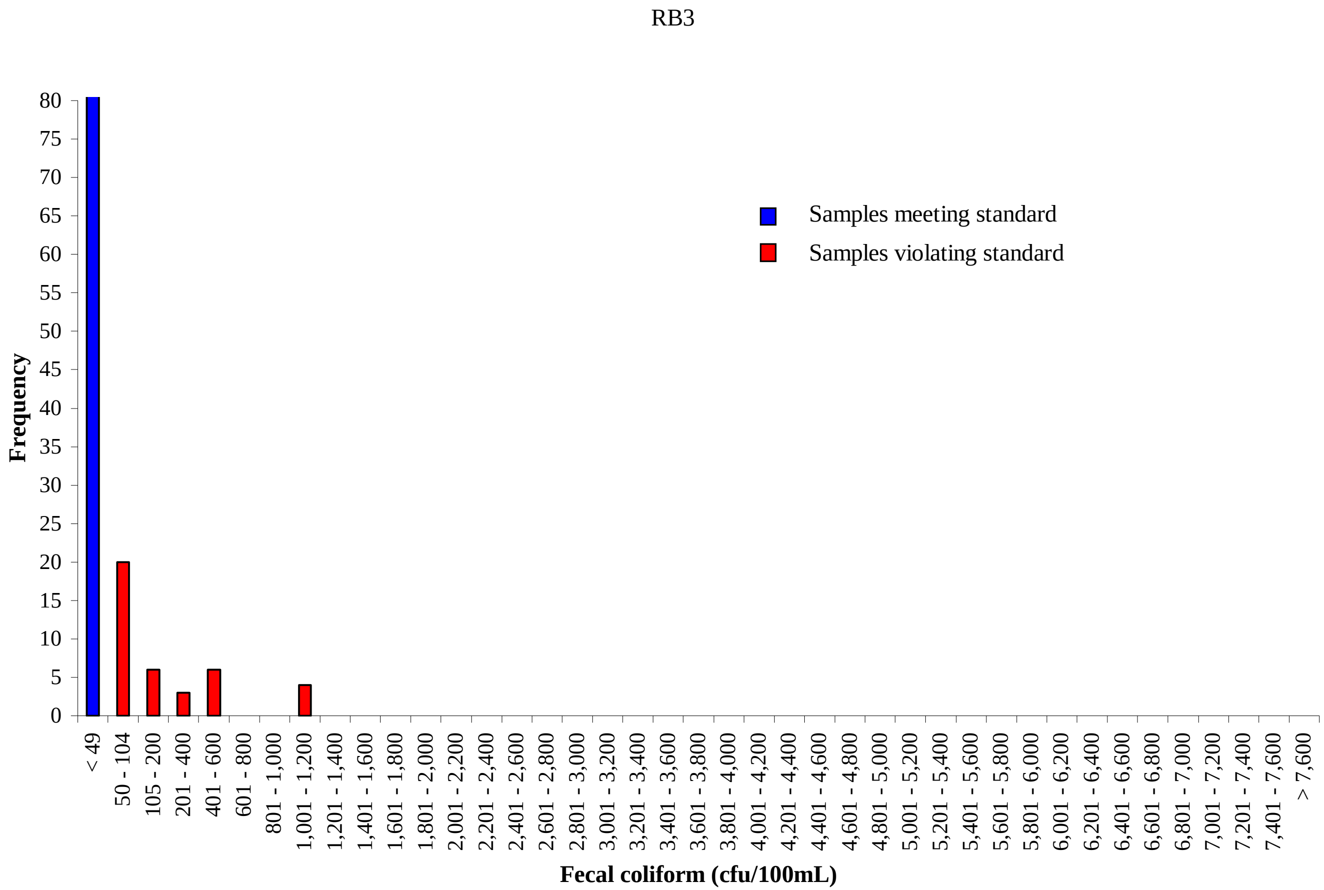

Figure A. 5 Frequency analysis of fecal coliform concentrations at station RB3 in Red Bank Creek for the period from February 1992 to July 2012. DSS monitoring station.

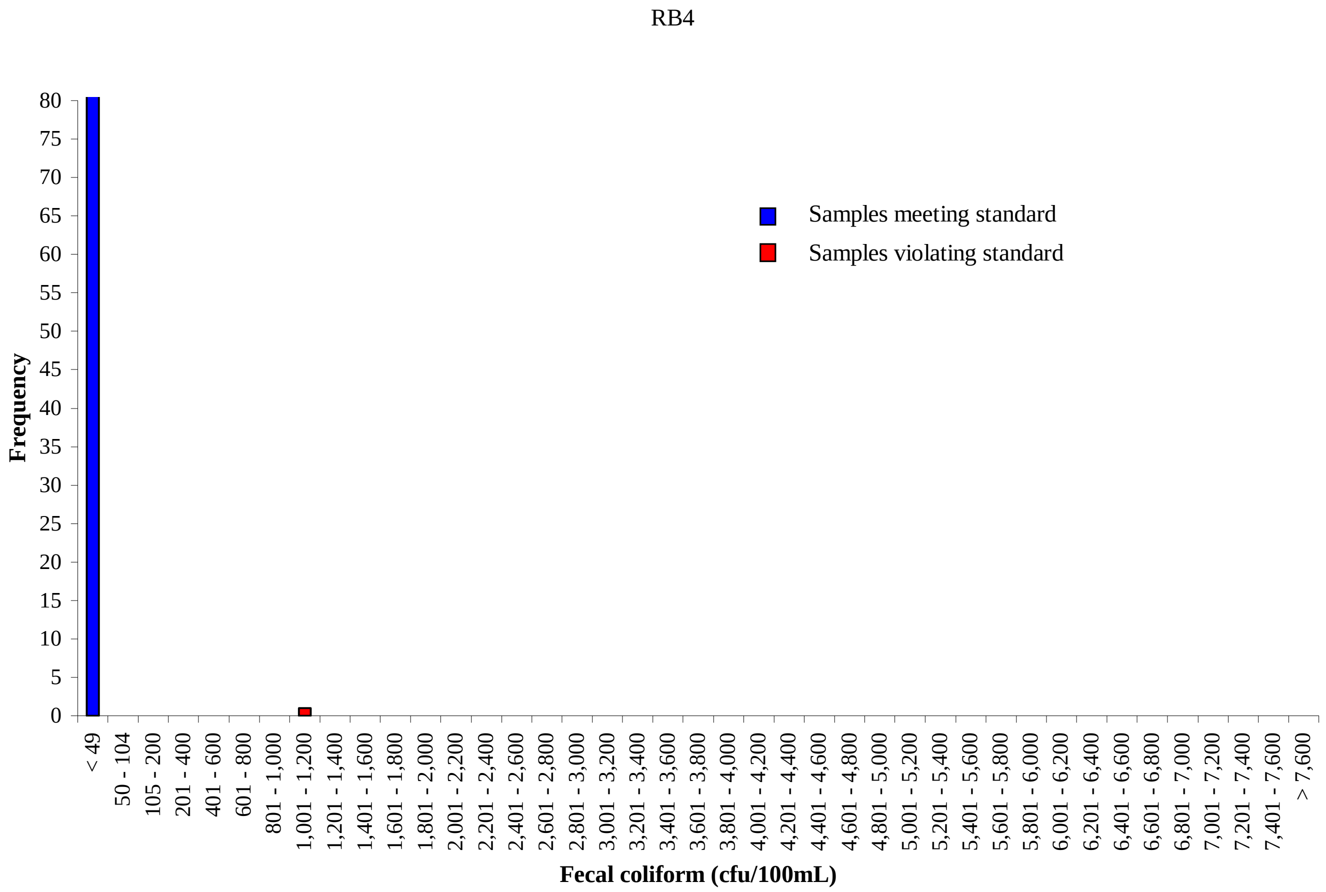

Figure A. 6 Frequency analysis of Fecal coliform concentrations at station RB4 in Red Bank Creek for the period from February 1992 to July 2012. DSS monitoring station.

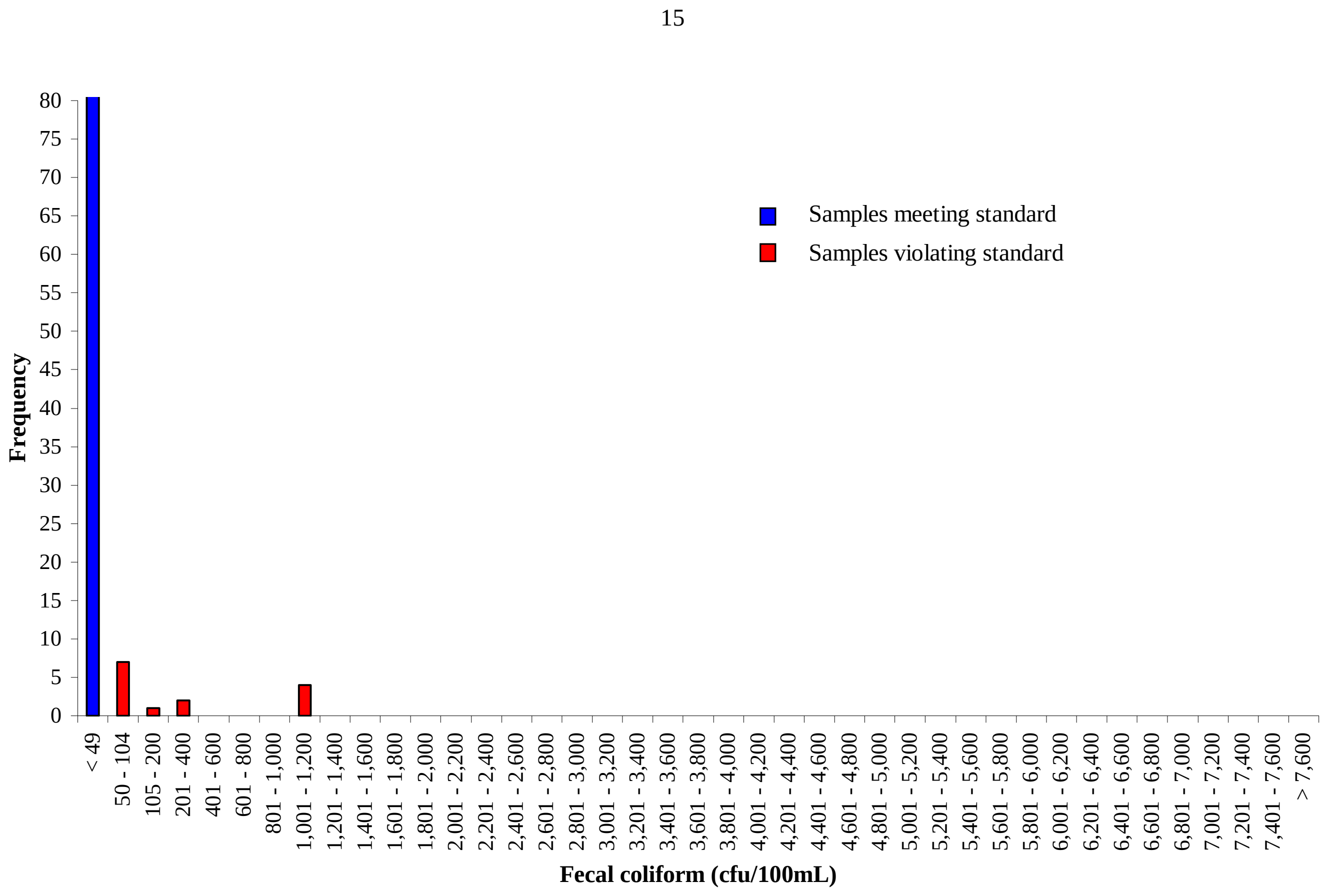

Figure A. 7 Frequency analysis of Fecal coliform concentrations at station 15 in the Machipongo River for the period from December 1984 to July 2012. DSS monitoring station.

APPENDIX B

Bacteria Modeling Procedure: Linking the Sources to the Endpoint

B. Bacteria Modeling Procedure: Linking the Sources to the Endpoint

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of the TMDL for the Red Bank Creek and Machipongo River watersheds study area, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are five basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality.

Due to the lack of continuous stream flow data for the study area, the model's hydrologic parameters were calibrated based on a paired watershed analysis. Through this approach, a hydrologically similar watershed, where continuous stream flow data is available, is chosen and modeled in the same manner as the study area. Flow is calibrated for the paired watershed by comparing model output to observed flow and making the proper adjustments to obtain the best match between simulated and observed flow. The changes between the initial estimated and final calibrated parameters from the paired watershed model are noted. Then, the estimated parameters in the impaired watershed model are changed by the same percentages. Once the flow component was built using this paired watershed approach, the bacteria concentration was calibrated by comparing model simulations of bacteria to observed bacteria values collected by VADEQ at five locations.

B.1. Modeling Framework Selection

The Red Bank Creek and Machipongo River watershed contains a broad range of hydrologic systems and thus requires a very robust and versatile modeling platform. The upstream areas are riverine segments, while downstream segments are tidally influenced and contain more swampland. The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate streamflow, overland runoff and to perform TMDL allocations in both the riverine and estuarine areas of the watershed.

The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

B.1.1. Modeling Free Flowing Streams

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

B.1.2. Modeling Tidal Impairments

The Steady State Tidal Prism Model, which is currently used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. MapTech's implementation of the Tidal Prism Model uses the same basic principle of a control volume with ebb and flood tides based on monitored data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody. Allocations can then be determined based directly in the 90^{th} percentile or geometric mean standard, as is applicable.

B.2. Model Setup

Daily precipitation data was available within the watershed at the Painter NCDC Coop station #446475. Missing values were filled using daily precipitation from the Wallops Island NCDC Coop station #448849. The final filled daily precipitation was disaggregated using hourly station data from Norfolk International Airport Coop station #446139.

To adequately represent the spatial variation in the watershed, the Red Bank Creek and Machipongo River watershed drainage area was divided into nine (9) subwatersheds (**Figure B. 1**). The rationale for choosing these subwatersheds was based on the availability of water quality data, the stream network configuration, and the limitations of the HSPF model. **Figure B. 1** shows all subwatersheds, which were used to achieve the unified model. **Table B. 1** notes the subwatersheds contained within each impairment, the impaired stream segments, and the outlet subwatershed for each impairment.

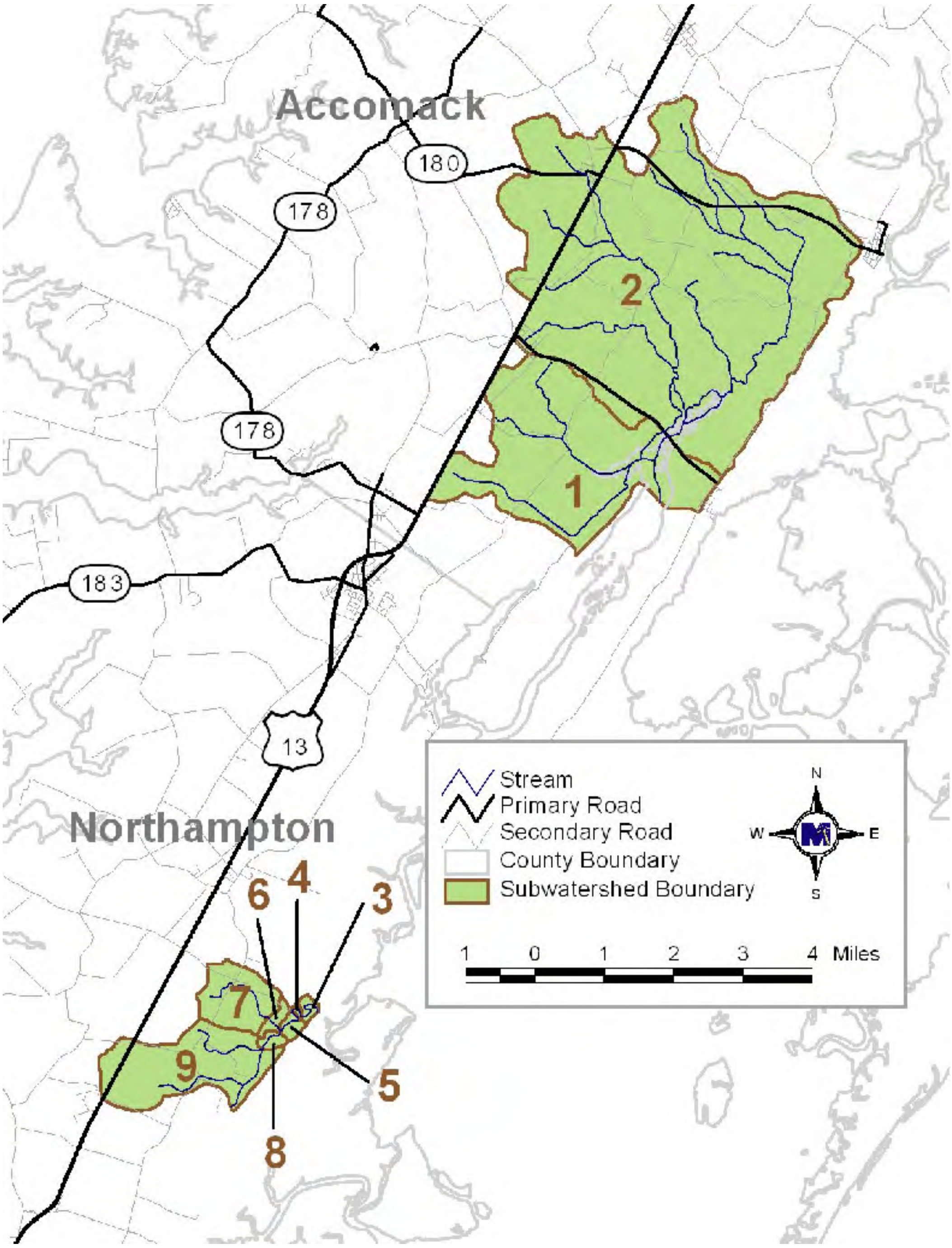

Figure B. 1 **All subwatersheds delineated for modeling in the Red Bank Creek and Machipongo River watershed study area.**

Table B. 1 Bacterial impairments and subwatersheds within the Red Bank Creek and Machipongo River watershed study area.

Impairment	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds
Machipongo River VAT-D04E_MAC01A00	1,2	1	1,2
Red Bank Creek VAT-D04R_RBC01A04	7	7	7
Red Bank Creek - Middle VAT-D04E_RBC02A08	5	5	4,5,6,7,8,9
Red Bank Creek - Middle VAT-D04E_RBC03A08	4	4	4,5,6,7,8,9
Red Bank Creek - Upper VAT-D04E_RBC04A08	3	3	3,4,5,6,7,8,9
*Machipongo River VAT-D04E_MAC01A00	1,2	1	1,2
*Red Bank Creek - Upper VAT-D04E_RBC01A08	6	6	6,7
*Red Bank Creek - Middle VAT-D04E_RBC02A08	5	5	4,5,6,7,8,9
*Red Bank Creek - Middle VAT-D04E_RBC03A08	4	4	4,5,6,7,8,9
*Red Bank Creek – UT** VAT-D04E_XDF01A04	8	8	8,9

* Denotes a shellfishing impairment, rather than a recreational impairment
**UT stands for unnamed tributary

In an effort to standardize modeling procedures across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

B.2.1. Land Uses

Nine land uses were identified in the watershed. These land uses were obtained by merging different sources including the MRLC land use grid, and aerial photography of the region. The nine land use types are given in **Table B. 2**. Within each subwatershed, up to the nine land use types were represented. Each land use in each subwatershed has hydrologic parameters (*e.g.*, average slope length) and pollutant behavior parameters (*e.g.*, fecal coliform accumulation rate) associated with it. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others vary with the season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

Table B. 2 Consolidated land use categories for the Red Bank Creek and Machipongo River watershed drainage area used in HSPF modeling.

TMDL Land use Categories	Pervious / Impervious (%)
Barren	Pervious (94%) Impervious (6%)
Cropland	Pervious (100%)
Commercial	Pervious (20%) Impervious (80%)
Forest	Pervious (100%)
Livestock Access	Pervious (100%)
Pasture	Pervious (100%)
Residential	Pervious (90%) Impervious (10%)
Wetlands	Pervious (100%)
Water	Pervious (100%)

Figure B. 2 shows the land uses used in modeling the Red Bank Creek and Machipongo River watersheds study area. **Table B. 3** shows the breakdown of land uses within the watershed. These acreages represent only what is within the boundaries of the Red Bank Creek and Machipongo River watershed study area.

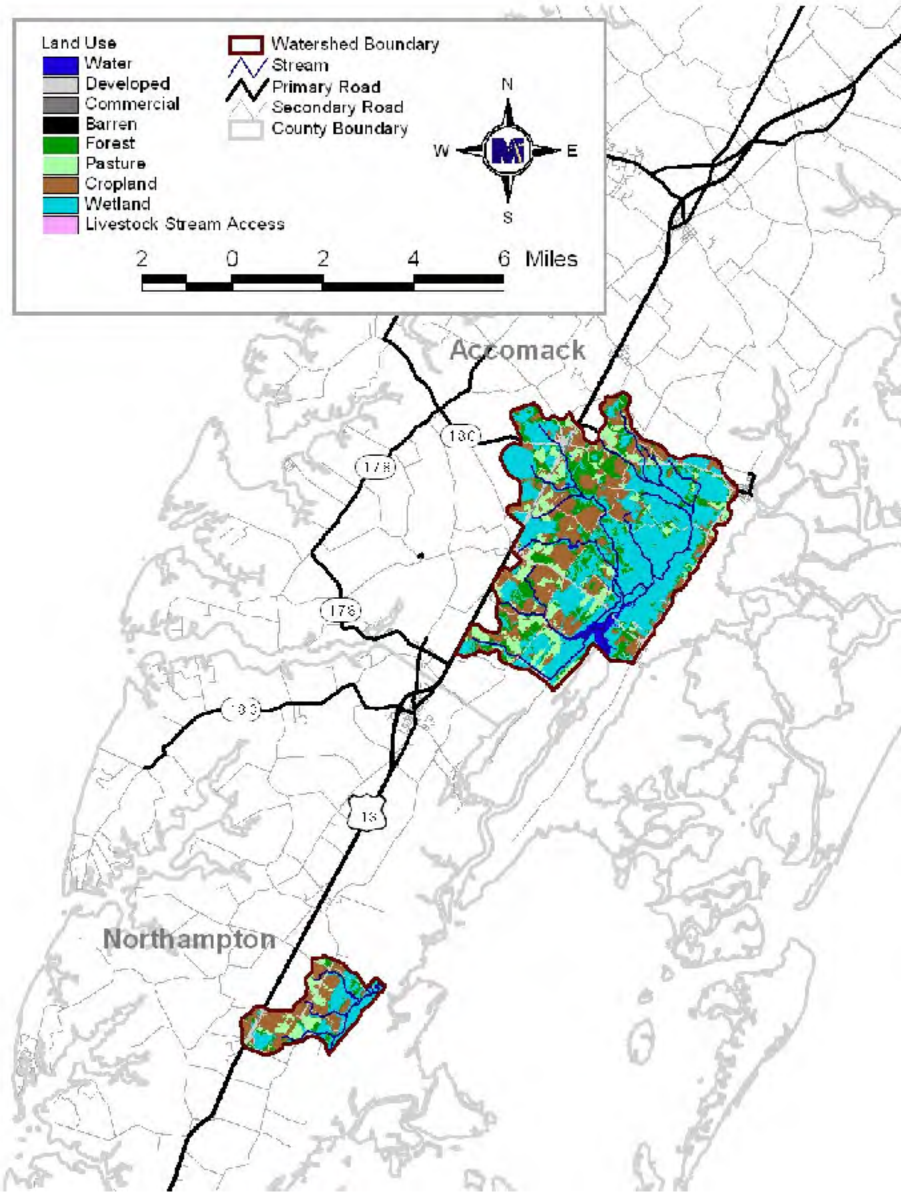

Figure B. 2 Land use in the Red Bank Creek and Machipongo River watershed study area.

Table B. 3 Spatial distribution of land use types in acres in the Red Bank Creek and Machipongo River watersheds study area.

Subwatershed	Water	Developed	Commercial	Barren	Forest	Pasture	Crop	Wet-land	LAX	Total
1	220.71	162.56	6.36	1.06	521.46	653.61	895.43	1156.60		3617.79
2	92.27	677.15	49.08	1.12	1523.50	891.22	2145.20	5177.49	3.52	10560.54
3	3.72	0.40			2.35	1.46		37.44		45.36
4	0.78	2.28			0.28	1.77		8.86		13.98
5	5.59	1.03			0.99		1.70	51.88		61.19
6	4.81	4.36			13.99		13.36	29.77		66.29
7	3.86	36.78			44.86	91.53	210.05	163.78	1.59	552.43
8	6.06				1.29		5.17	40.86		53.38
9	13.53	124.92	7.02		128.22	194.12	524.06	359.19	0.11	1351.17
Total	351.33	1009.48	62.45	2.19	2236.94	1833.69	3794.96	7025.86	5.22	16322.13

LAX is livestock access to a stream.

Die-off of fecal bacteria can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal bacteria entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

B.2.2. Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). These data are entered into HSPF via the Hydraulic Function Tables (F-tables). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and discharge (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume in the reach, and is reported in acre-feet. The discharge is simply the stream outflow, in cubic feet per second.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2010), Digital Elevation Models (DEM), nautical charts, and bathymetry data was used. The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the Red Bank Creek and Machipongo River watersheds. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each non-tidal subwatershed outlet.

The other entries in each non-tidal F-table and all entries in the tidal F-tables were calculated from the DEM and bathymetry data. A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet (**Figure B. 3**). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example of an F-table used in HSPF is shown in **Table B. 4**.

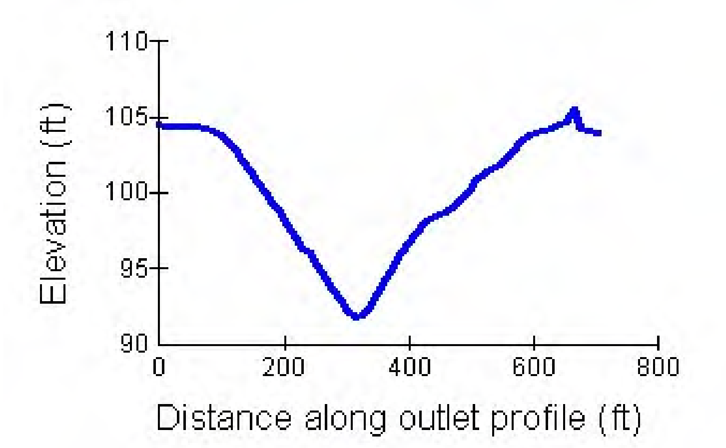

Figure B. 3 Stream profile representation in HSPF.

Table B. 4 Example of an F-table calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
3.28	0.71	1.41	17.07
6.56	1.89	5.15	45.23
9.84	2.54	12.18	85.02
13.12	4.77	24.80	152.82
16.40	56.55	77.51	637.72
19.68	1,047.22	1,635.10	18,846.85
22.96	2,875.31	7,405.99	69,827.77
26.24	3,495.32	18,464.40	133,806.76
29.52	4,426.89	31,720.10	160,393.97

B.3. Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.,* population). Depending on the timeframe of the simulation being run, different estimates were used. Data were obtained for the appropriate timeframe for water quality calibration and validation. Data representing 2012 were used for the allocation runs in order to represent current conditions.

B.3.1. Permitted Sources

No point sources are permitted to discharge water into surface waters in the Red Bank Creek and Machipongo River watershed study area through the Virginia Pollutant Discharge Elimination System (VPDES) that contain fecal bacteria.

There is one confined animal feeding operation (CAFO) facility in the area (VPG250063). Manure from this facility was spread on cropland in the study area, which is elaborated in the following sections.

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

B.3.2. Private Residential Sewage Treatment

The number of septic systems in the Red Bank Creek and Machipongo River watersheds study area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000; USCB 2010) with the subwatersheds. During allocation runs, the number of households was projected to 2012, based on current growth rates (USCB, 2010) resulting in 798 septic systems and 28 straight pipes (**Table B. 5**).

Table B. 5 Estimated failing septic systems and straight pipes for 2012 in the Red Bank Creek and Machipongo River watersheds study area.

Subwatershed	Septic Systems	Failing Septic Systems	Straight Pipes
1	215	7	9
2	58	15	19
3	1	0	0
4	0	0	0
5	1	0	0
6	5	0	0
7	31	1	0
8	0	0	0
9	87	3	0
Total	**798**	**26**	**28**

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. The initial estimates of the number of failing septic systems were based on the assumption that each septic system fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with the region's Health Departments and feedback was obtained and used in adjusting numbers. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

Straight pipes were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Initial estimates obtained using this method were shared with the region's Health Departments and feedback was obtained and used in adjusting numbers. The loadings from straight pipes were modeled in the same manner as direct discharges to the stream.

B.3.3. Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Different livestock populations were estimated for each water quality modeling period (calibration/validation/allocation). The numbers are based on data provided by Virginia Agricultural Statistics (VASS), with values updated and discussed by VADCR, NRCS and SWCDs as well as taking into account growth rates in these counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1997; VASS, 2002). For land-applied collected waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for direct deposition on land and to streams (**Table 3.5**). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

Land Application of Collected Manure

The average daily waste production for the poultry operation was calculated using the number of animal units, weight of animal, and waste production rate as reported in **Section 3.3.4**. This information along with a die-off factor to account for bacterial death during storage was used to calculate the amount of waste available to be spread on cropland. The proportion of waste available from the poultry operation that was applied within the watershed was calculated based on information made available by VADEQ on the application sites and rates within the watershed study area. Stored waste was spread on cropland only. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR (MapTech, Inc., 2002). The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse, sheep) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land was area-weighted.

Direct Deposition to Streams

The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

B.3.4. Biosolids

Investigation of VADEQ data indicated that biosolids applications have not occurred within the Red Bank Creek and Machipongo River watersheds study area during the modeling periods.

B.3.5. Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (**Section 3.3.5**). An example of one of these layers is shown in **Figure B. 4**. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

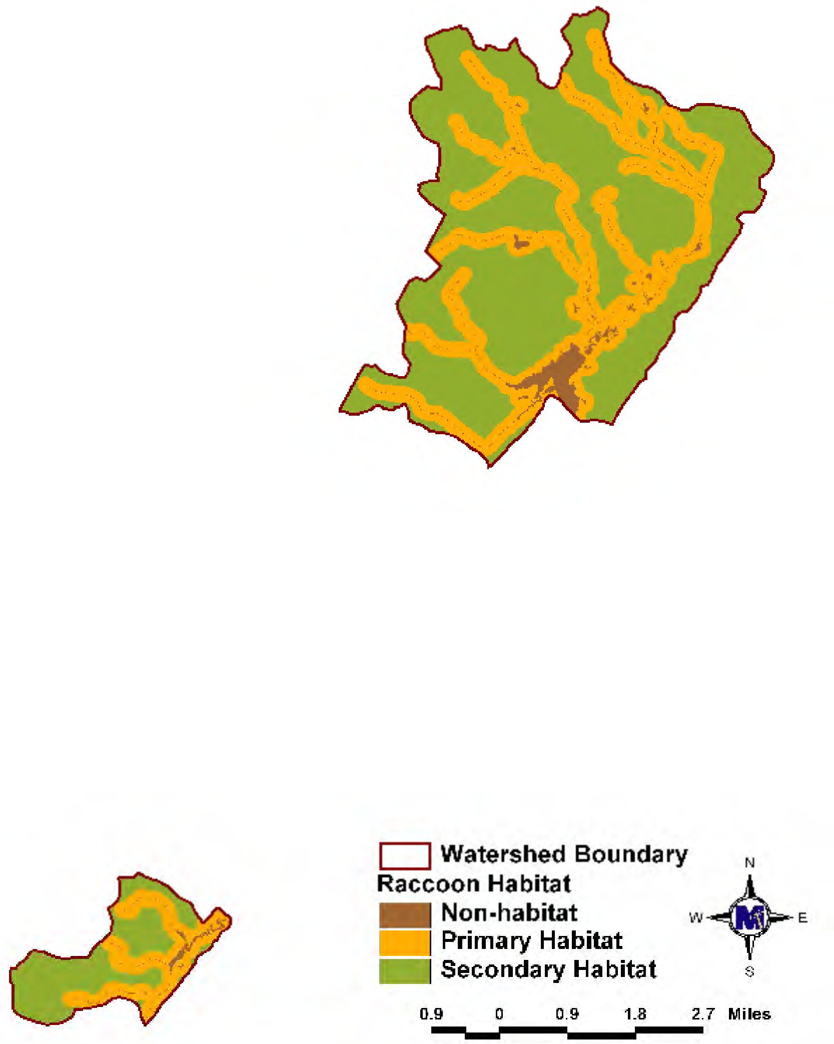

Figure B. 4 Example of raccoon habitat layer in the Red Bank Creek and Machipongo River watersheds study area, as developed by MapTech.

For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (**Table 3.11**). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams.

B.3.6. Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in **Section 3.3.3**. Waste from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 2010 Census (USCB, 1990 and USCB, 2010). The number of animals per subwatershed was determined by multiplying the number of households by the pet population density. The amount of fecal coliform deposited daily by pets in each subwatershed was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 2010 data to 2012.

B.4. Bacteria TMDL Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the Red Bank Creek and Machipongo River watersheds study area is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the Red Bank Creek and Machipongo River watersheds study area are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources in this context also include nonpoint sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A description of the data used in these analyses is shown in **Table 2.1** in **Chapter 2**. Graphical analyses of fecal bacteria concentrations and flow duration intervals showed that water quality standard violations occurred in a range of conditions at four (4) VADEQ monitoring stations in the Red Bank Creek and Machipongo River watersheds study area (**Figure B. 5** and **Figure B. 6**). This demonstrates that this stream should have all flow regimes represented in the allocation modeling time period. As there were no flow gages available within the watershed to pair with the monitored bacteria data, flow data from the nearby reference watershed was used.

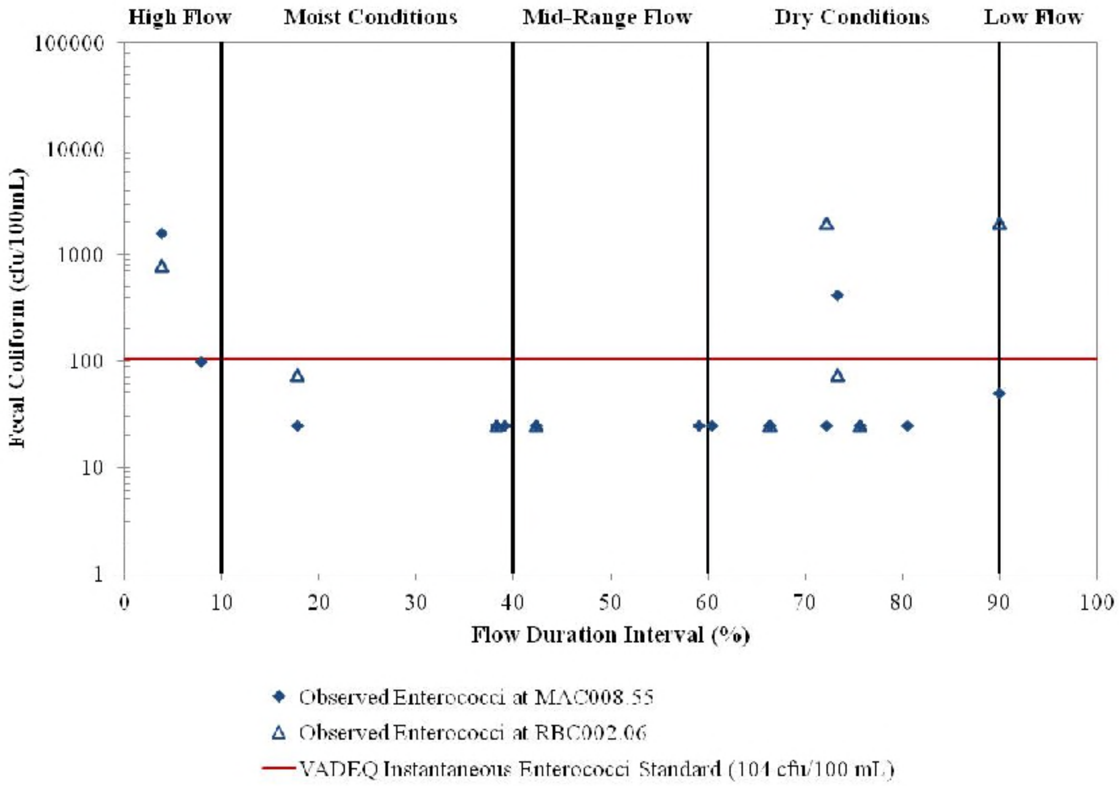

Figure B. 5 Enterococci bacteria concentrations at MAC008.55 and RBC002.06 in the Red Bank Creek and Machipongo River watershed versus discharge at USGS Gaging Station #01485500.

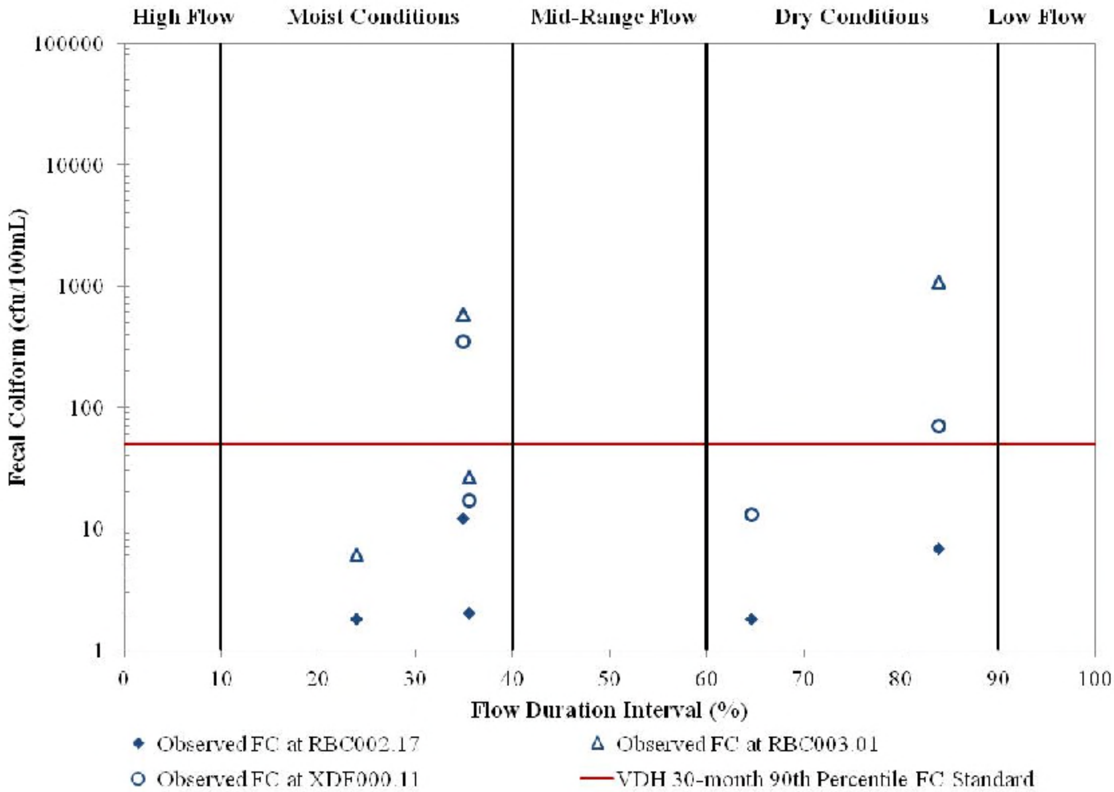

Figure B. 6 Fecal bacteria concentrations at RBC002.17, RBC003.01, and XDF000.11 on Red Bank Creek and tributaries versus discharge at USGS Gaging Station #01485500.

Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area.

B.5. Selection of Paired Watershed

There are many factors to consider when finding a best-fit paired watershed. Drainage area, shape, proximity to the impaired watershed, land use, hydrologic soil group, ecoregion, and slope are among the most important. Four watersheds were compared to choose the best fit to the Red Bank Creek-Machipongo watershed: Nassawadox Creek (in Worchester and Wicomico Counties, MD), Manokin Branch (in Somerset Count, MD), Piscataway Creek (Essex County, VA), and St. Marys River (in St. Mary's County, MD).

These four were originally chosen for their proximity to the Red Bank Creek and Machipongo River watersheds and the availability of flow data for each.

Though both Piscataway Creek and St. Marys River were of similar size to the Red Bank Creek-Machipongo watershed, both were located further inland on the western side of the Chesapeake Bay rather than on the eastern shore near the impaired watershed. Also, both Pisctataway Creek and St. Marys River watersheds contained a significantly greater proportion of developed land than the Red Bank Creek and Machipongo River watershed.

Manokin Branch and Nassawadox Creek are both located approximately 50 miles north of the Red Bank Creek-Machipongo watershed on the Delmarva Peninsula, and each have similar land use distributions to the impaired watershed. However, the Manokin Branch watershed being compared is less than one quarter the size of the impaired watershed. The Nassawadox Creek watershed under consideration was approximately 1.85 times the size of the impaired watershed, but this was considered more acceptable for comparison than the much smaller Manokin Branch watershed.

The first action taken to implement the paired watershed approach was examining the similarities between the Nassawadox Creek and Red Bank Creek and Machipongo River watersheds. The land use distribution is shown in **Table B. 6**.

Table B. 6 Land use distribution for Red Bank Creek-Machipongo River and Nassawadox Creek watersheds.

Land Use	Red Bank Creek and Machipongo River		Nassawadox Creek	
	acres	percent	acres	percent
Water	358.75	2.19	128.24	0.43
Developed	1025.73	6.27	1229.81	4.11
Commercial	70.32	0.43	12.15	0.04
Barren	3.56	0.02	14.59	0.05
Forest	2288.19	13.98	8390.61	28.06
Pasture	1852.75	11.32	1073.04	3.59
Cropland	3843.18	23.47	4159.62	13.91
Wetland	6929.77	42.33	14890.51	49.80

The soil hydrologic groups in both watersheds were examined. The soils present in both the Nassawadox Creek and Red Bank Creek and Machipongo River watersheds consisted largely of sandy clay loams. Based on hydrologic soil group classification, the soil series present in the Nassawadox Creek watershed ranges from "B" to "C". The soil series present in the Red Bank Creek and Machipongo River watersheds ranged from "C" to "D", with "C" being the predominant classification.

The Nassawadox Creek watershed lies entirely in the Delmarva Uplands ecoregion, while the Red Bank Creek-Machipongo River watershed is divided between the Delmarva Uplands and the Virginia Barrier Islands and Coastal Marshes ecoregion (**Table B. 7**). However, both of these ecoregions are included in the larger Middle Atlantic Coastal Plain ecoregion. The average watershed slope and aspect are also compared in **Table B. 7** and were very similar between the two watersheds.

Table B. 7 Comparison of Red Bank Creek-Machipongo River and Nassawadox Creek watershed characteristics.

Watershed	Total Acreage	Average Watershed Slope (degrees)	Average Water-shed Aspect (degrees)	EcoRegion
Red Bank Creek - Machipongo River	16,372	0.3707	166.6	44% Delmarva Uplands, 56% Virginia Barrier Islands and Coastal Marshes
Nassawadox Creek	29,896	0.4896	179	100% Delmarva Uplands

Based on the land use distribution, soil types, ecoregion, and the watershed's physical characteristics, the Nassawadox Creek watershed is considered hydrologically similar to the Red Bank Creek and Machipongo River watersheds.

B.6. Selection of Representative Modeling Periods

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Modeling periods were selected for hydrology calibration and validation, water quality calibration and validation, and modeling of allocation scenarios. Due to the lack of flow data for the impaired watershed, a paired approach was used for hydrology calibration and validation. As shown in the critical conditions section (**Figure B. 5** and **Figure B. 6**), there is no single critical flow level where the majority of the bacterial standard exceedances occurred. This indicates that the modeling time periods must include low and high stream flow regimes.

Representative flow periods were chosen for hydrology calibration and validation based on precipitation and flow data for the paired watershed, Nassawadox Creek. Daily precipitation data was available near the Nassawadox Creek watershed at Salisbury Wicomico Regional Airport NCDC Coop station #093720. The few missing values were filled with daily precipitation from the Snow Hill NCDC Coop #188380, with any remaining gaps filled with daily precipitation data from the Princess Anne NCDC Coop station #187330. Continuous stream flow data was available at the outlet of the watershed at USGS station #01485500 on Nassawadox Creek near Snow Hill, MD from 12/1/1949-6/30/2013. The hydrologic calibration period was chosen to be October 1990 through September 1993, and the hydrologic validation period was chosen to be October 2002 through September 2007. The hydrology calibration and validation periods have a range of both high and low stream flow and precipitation, which represent the high and low flow critical regimes (**Figure B. 7** and **Figure B. 8**). The figures are shown here to demonstrate the historical annual and seasonal stream flow and precipitation and how the selected time periods encompass a representative range of values. **Table B. 8** shows the statistical comparison between calibration/validation time periods and historic time period.

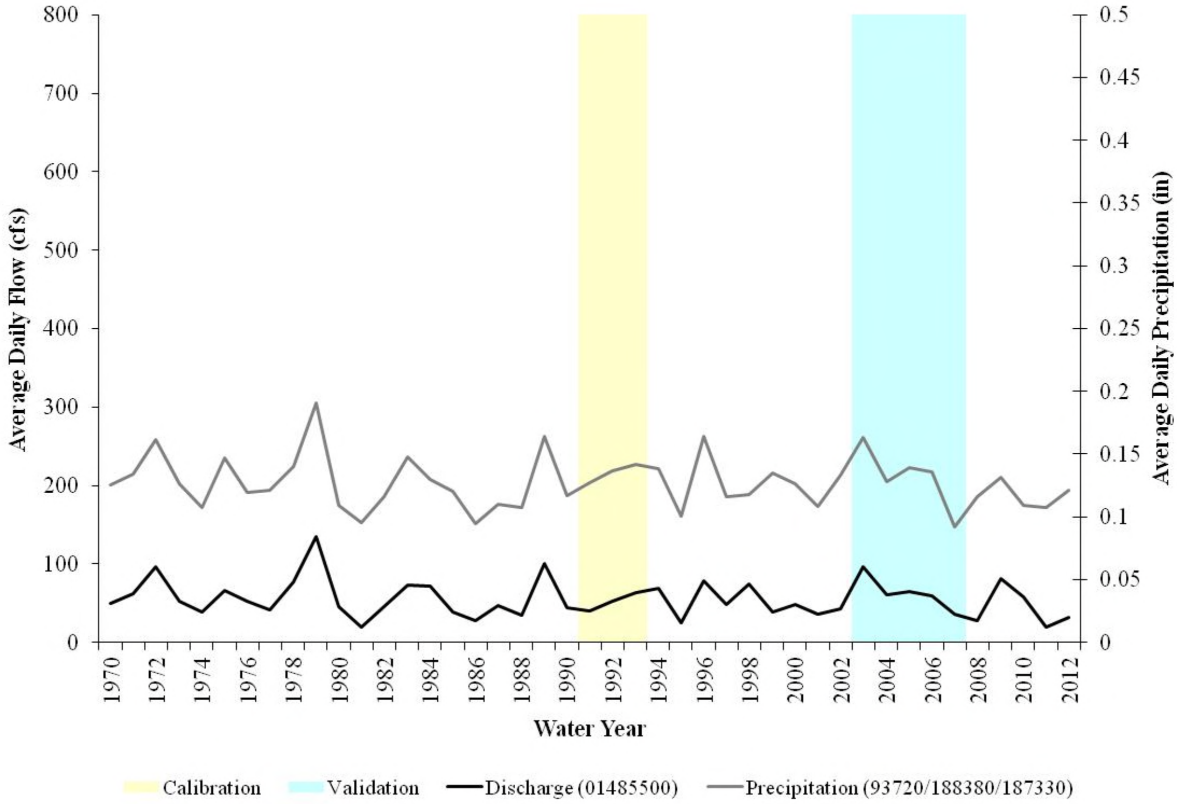

Figure B. 7 **Hydrology calibration and validation time periods, annual historical flow (USGS Station 01485500), and precipitation (Station 93720/188380/187330) data.**

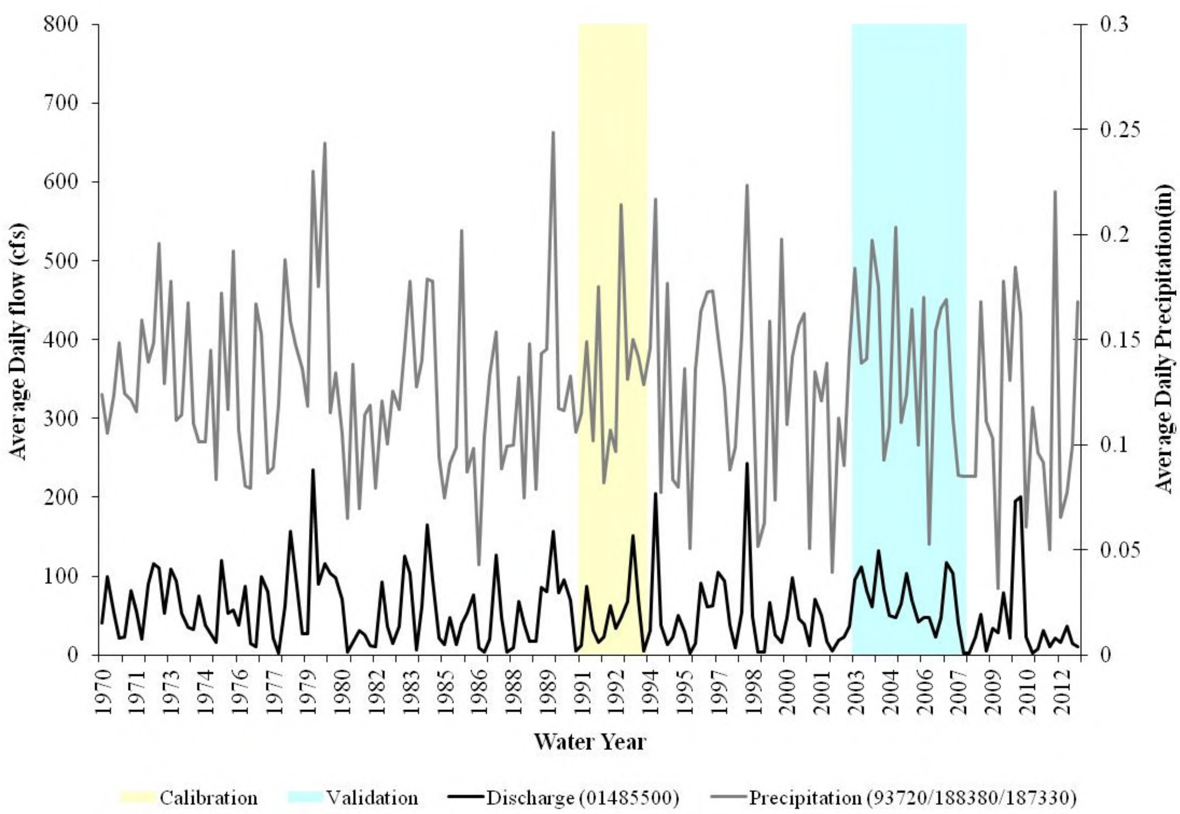

Figure B. 8 Hydrology calibration and validation time periods, seasonal historical flow (USGS Station 01485500), and precipitation (Station 93720/188380/187330) data.

Table B. 8 Comparison of modeled period to historical records for the Nassawadox Creek watershed.

	Discharge (01485500)				Precipitation (93720/188380/187330)			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Historical Record (1949-2013)				**Historical Record (1948-2013)**			
Mean	44	96	48	26	0.113	0.122	0.113	0.148
Variance	1,410	2,590	689	794	0.001	0.002	0.001	0.002
	Calibration and Validation Time Periods (10/90-9/93,10/03-9/06)				**Calibration and Validation Time Periods (10/90-9/93,10/03-9/06)**			
Mean	70	94	50	34	0.142	0.116	0.124	0.158
Variance	1,849	1,008	466	512	0.001	0.001	0.001	0.002
	p-values				**p-values**			
Mean	0.053	0.445	0.395	0.199	0.023	0.300	0.159	0.278
Variance	0.260	0.095	0.309	0.283	0.410	0.323	0.314	0.390

Availability of water quality data was a limiting factor in choosing a representative period for water quality calibration for the Red Bank Creek and Machipongo River watershed. Both DEQ and VDH data were considered in determining the water quality calibration and validation periods to maximize the number of data points available. The period containing the greatest amount of monitored data dispersed over the most stations was chosen as the calibration period, October 2003 through September 2007. The period contained 229 data points. The period from October 1999 through September 2003 was chosen as the validation period, with 185 data points. **Figure B. 9** and **Figure B. 10** are shown here to demonstrate the historical annual and seasonal stream flow and precipitation and how the selected time periods encompass a representative range of values. **Table B. 9** shows the statistical comparison between the water quality calibration and validation time periods and historic time period.

The TMDL allocation period was chosen to be October 1999 through September 2003, the same as the water quality validation period. Using the water quality validation period as the allocation period allows the TMDL allocations to be determined during the period that the most confidence can be placed in the model while still maintaining the most representative hydrologic period possible.

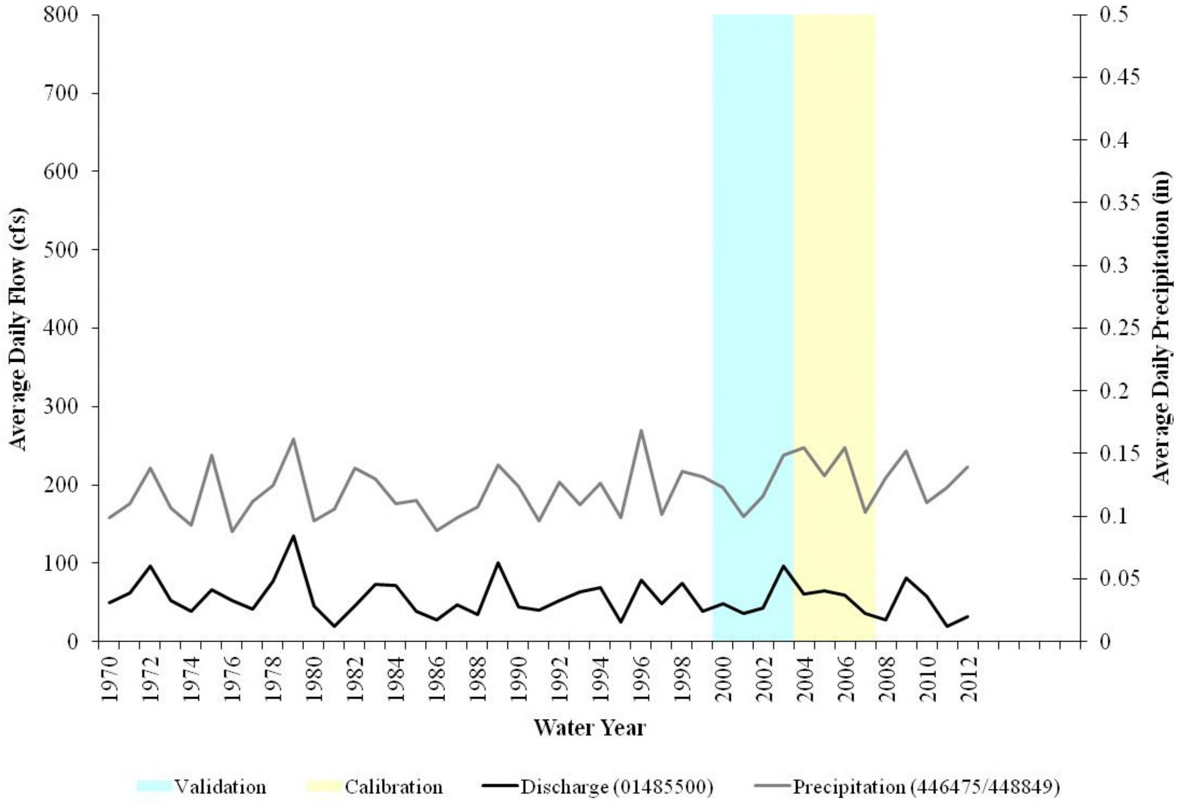

Figure B. 9 Water quality calibration and validation time periods, annual historical flow (USGS Station 01485500), and precipitation (Station 446475/448849) data.

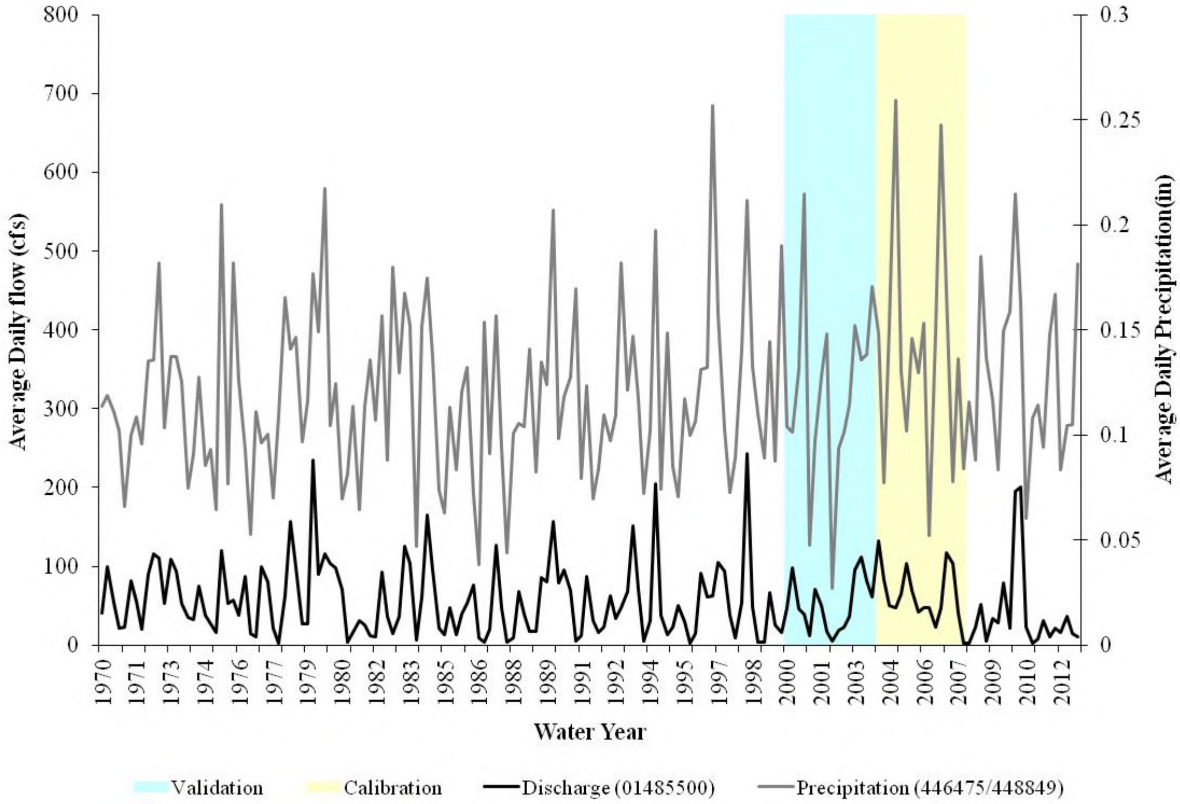

Figure B. 10 Water quality calibration and validation time periods, seasonal historical flow (USGS Station 01485500), and precipitation (Station 446475/448849) data.

Table B. 9 Comparison of modeled period to historical records for the Red Bank Creek and Machipongo River watershed.

Discharge (01485500)				Precipitation (446475/448849)			
Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Historical Record (1950 - 2013)				Historical Record (1955-2013)			
43	95	48	26	0.111	0.121	0.111	0.134
1,408	2,589	689	794	0.002	0.001	0.001	0.003
Calibration and Validation Time Periods (10/03-9/07; 10/99-9/03)				Calibration and Validation Time Periods (10/03-9/07; 10/99-9/03)			
65	79	48	37	0.116	0.092	0.135	0.171
2,179	1,035	423	352	0.003	0.001	0.000	0.004
p-values				p-values			
0.104	0.107	0.495	0.081	0.397	0.003	0.001	0.060
0.168	0.101	0.258	0.129	0.099	0.145	0.017	0.218

B.7. Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

B.7.1. Hydrologic Calibration and Validation

The paired watershed approach was used to calibrate the HSPF model. Through this approach, an HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow data is available. The changes between the initial estimated and final calibrated parameters from the paired watershed model (e.g. lower zone storage) are noted. Then, the estimated parameters in the impaired watershed HSPF model are changed by the same percentages. Selection of Nassawadox Creek as the paired watershed for the Red Bank Creek and Machipongo River watersheds is covered in an earlier section of this appendix. The Nassawadox Creek model was calibrated for hydrologic accuracy using daily flow data for October 1990 through September 1993.

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (LSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), groundwater recession flow (KVARY), and active groundwater storage PET (AGWETP). **Table B. 10** contains the possible range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

Table B. 10 Initial hydrologic parameters estimated for the Red Bank Creek and Machipongo River watershed study area and resulting final values after calibration.

Parameter	Units	Possible Range of Parameter Value	Initial Parameter Estimate	Final Calibrated Parameter Value
LZSN	in	2.0 – 15.0	7	4.9
INFILT	in/hr	0.001 – 0.50	0.0285 - 0.2479	0.0256 - 0.2231
KVARY	1/in	0.0 – 5.0	0.01	0.01
AGWRC	1/day	0.85 – 0.999	1	2
DEEPFR	---	0.0 – 0.50	0.01	0.32
BASETP	---	0.0 – 0.20	0.98	0.92
AGWETP	---	0.0 – 0.20	0	0
INTFW	---	1.0 – 10.0	0 - 0.2	0 - 0.3
IRC	1/day	0.30 – 0.85	0.2 - 0.5	0.02 - 0.05
MON-INTERCEPT	in	0.01 – 0.40	0 - 0.8	0 – 0.8
MON-UZSN	in	0.05 – 2.0	7	4.9
MON-LZETP	---	0.1 – 0.9	0.0285 - 0.2479	0.0256 - 0.2231

Table B. 11 shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated. **Figure B. 11** and **Figure B. 12** graphically show these comparisons.

Table B. 11 Hydrology calibration model performance from 10/1/1990 through 9/30/1993 at USGS Gaging Station #1485500 on Nassawadox Creek.

Criterion*	Observed	Modeled	Error
Total In-stream Flow	43.99	45.87	4.28%
Upper 10% Flow Values	21.77	21.21	-2.55%
Lower 50% Flow Values	4.32	4.72	9.26%
Winter Flow Volume	21.49	19.30	-10.20%
Spring Flow Volume	9.93	9.97	0.38%
Summer Flow Volume	5.04	7.24	43.60%
Fall Flow Volume	7.53	9.37	24.40%
Total Storm Volume	42.16	44.63	5.85%
Winter Storm Volume	21.04	18.99	-9.72%
Spring Storm Volume	9.48	9.66	1.91%
Summer Storm Volume	4.58	6.93	51.20%
Fall Storm Volume	7.07	9.05	28.08%

*Flow value units are cfs, flow volume units are in.

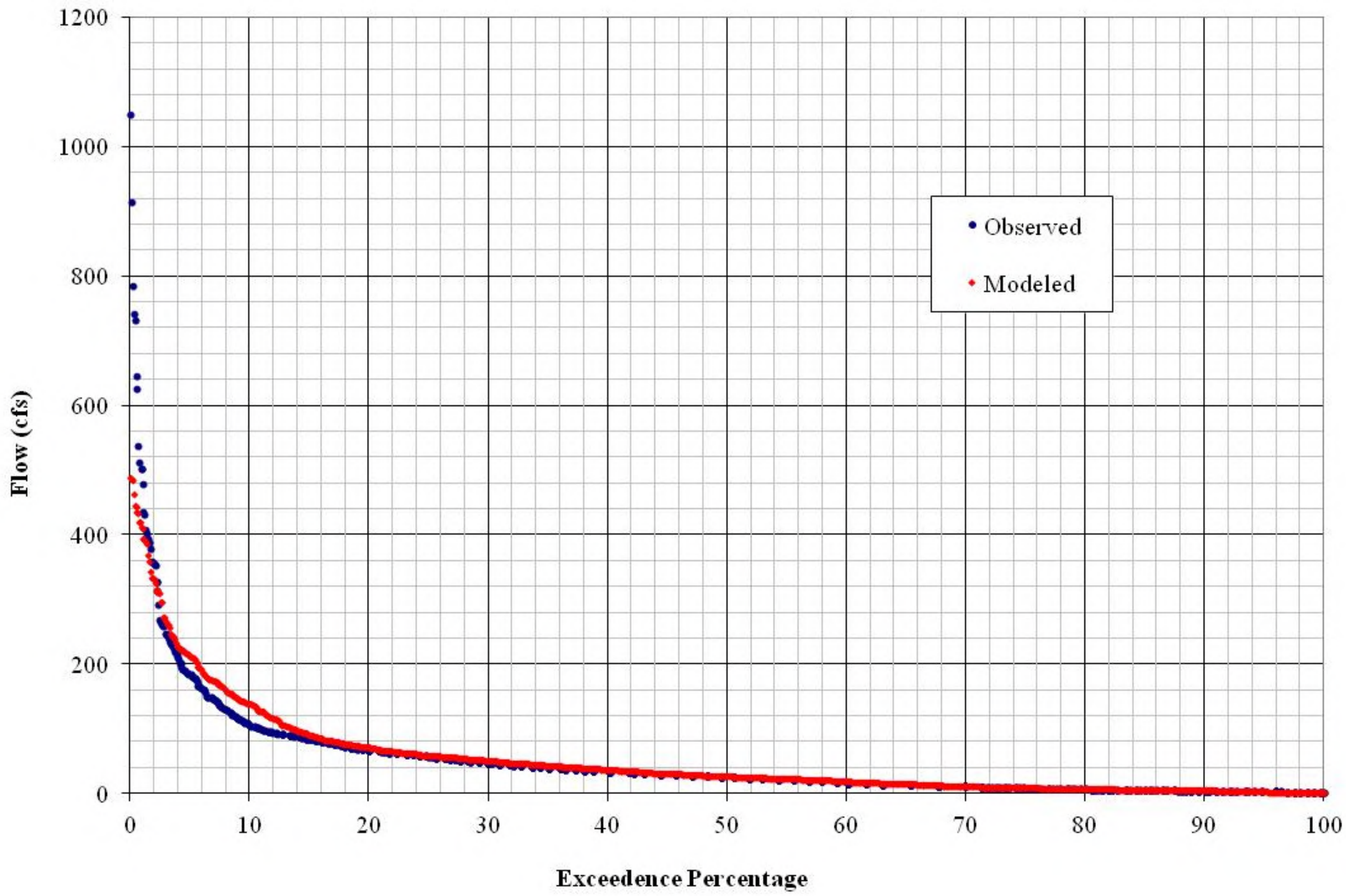

Figure B. 11 **Nassawadox Creek modeled flow duration versus USGS Gaging Station #01485500 data from 10/1/1990 to 9/30/1993 for calibration.**

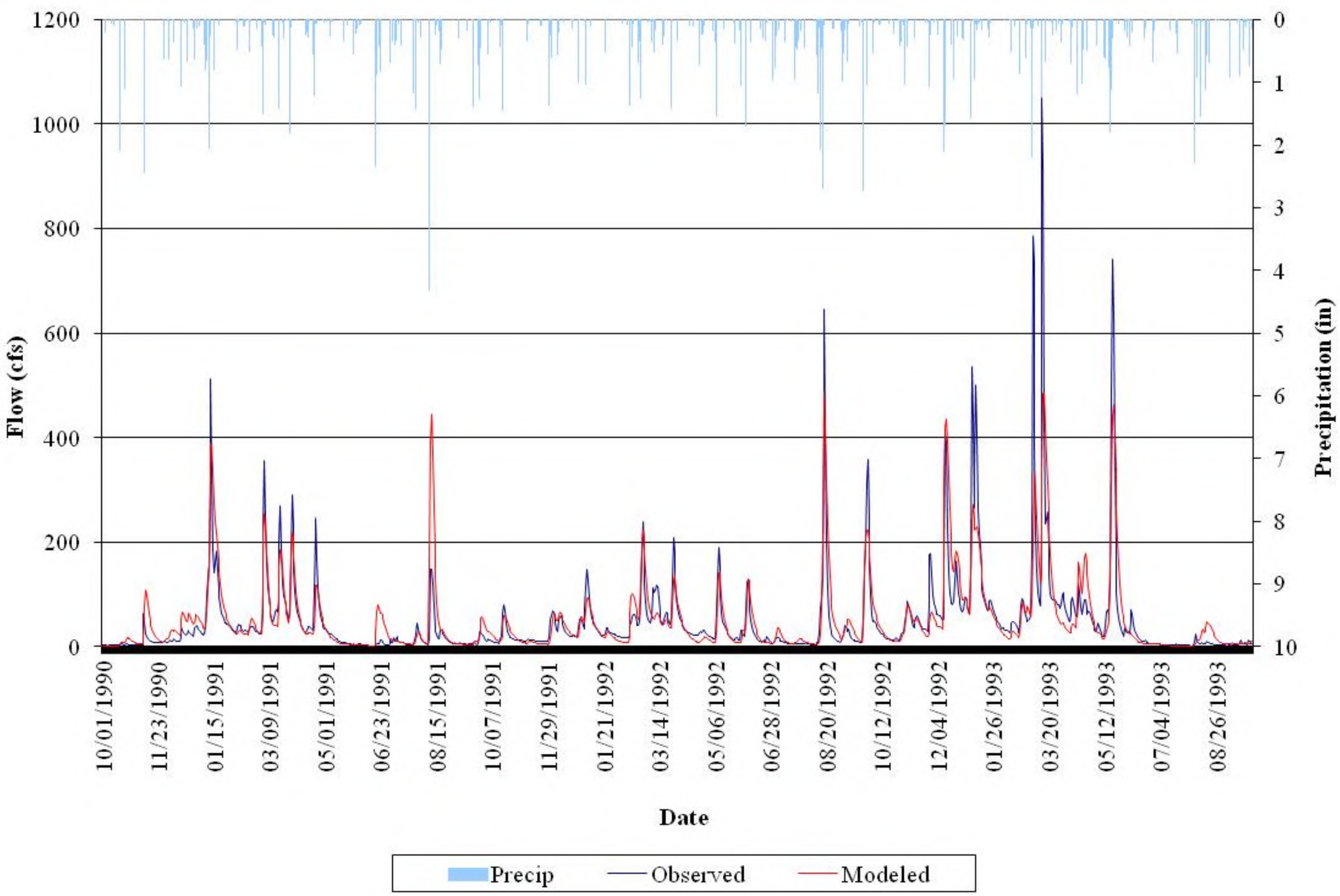

Figure B. 12 Nassawadox Creek modeled results versus USGS Gaging Station #01485500 data from 10/1/1990 to 9/30/1993 for calibration.

The modeled output was validated for the period of October 2002 through September 2007. Simulated flow at the outlet was compared with daily flow at the Nassawadox Creek USGS Gaging Station #01485500. **Table B. 12** shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated and has been validated during a different time period. The lack of representative precipitation gaging stations that cover different parts of the watershed is the main reason the error in summer flows is elevated. Summer storms tend to be localized and intense and therefore, simulated flow rate generated using limited rainfall data may not match well with observed flow in the stream itself. **Figure B. 13** and **Figure B. 14** graphically show these comparisons.

Table B. 12 Hydrology validation model performance from 10/1/2002 through 9/30/2007 at USGS Gaging Station #01485500 on Nassawadox Creek.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	99.55	95.56	-4.00%
Upper 10% Flow Values:	42.71	37.79	-11.52%
Lower 50% Flow Values:	12.26	10.35	-15.57%
Winter Flow Volume	32.09	25.89	-19.33%
Spring Flow Volume	19.24	18.71	-2.73%
Summer Flow Volume	14.69	17.85	21.51%
Fall Flow Volume	33.53	33.11	-1.25%
Total Storm Volume	97.14	93.74	-3.51%
Winter Storm Volume	31.49	25.44	-19.23%
Spring Storm Volume	18.63	18.25	-2.03%
Summer Storm Volume	14.09	17.39	23.40%
Fall Storm Volume	32.92	32.65	-0.81%

*Flow value units are cfs, flow volume units are in.

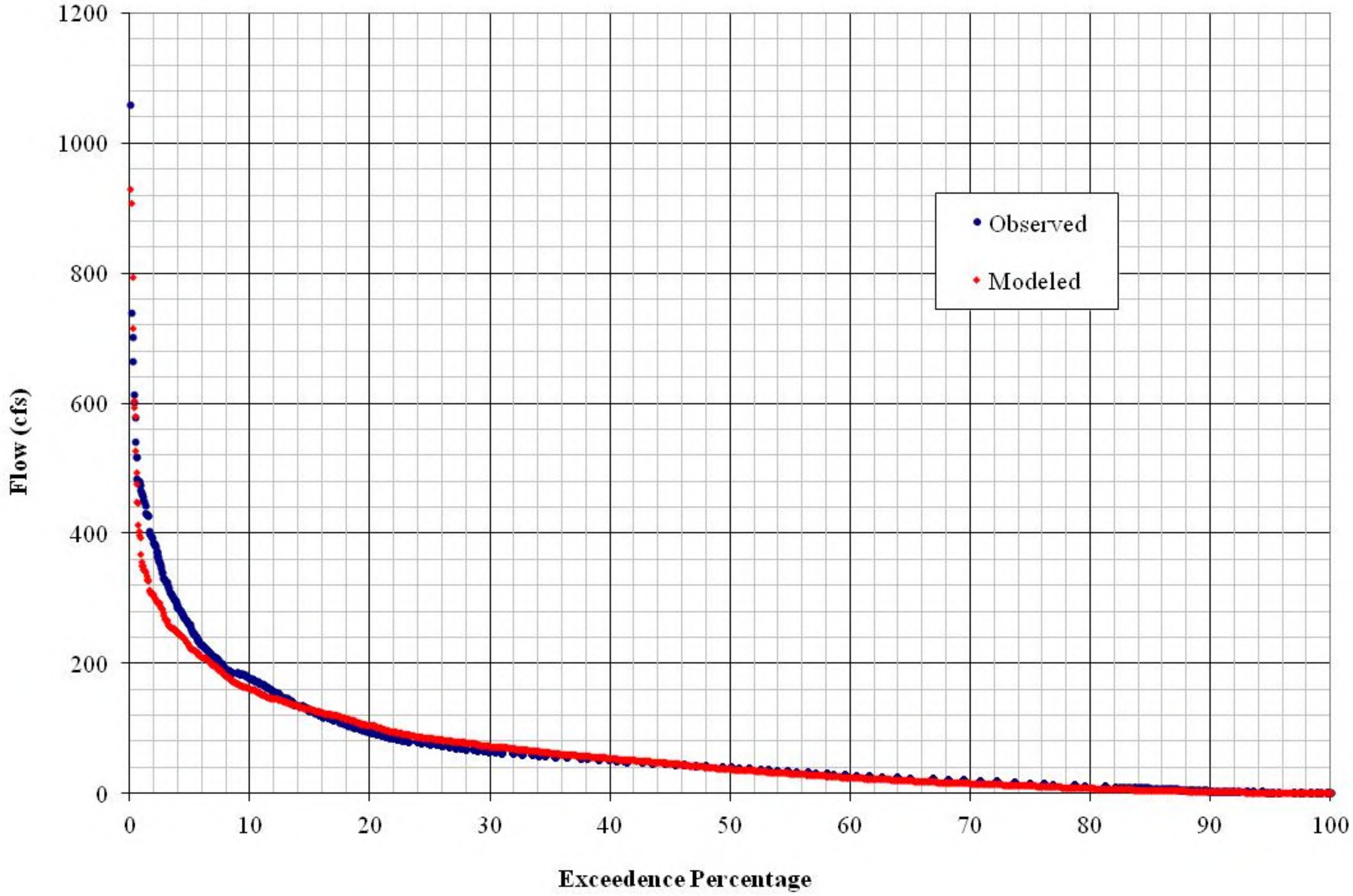

Figure B. 13 Nassawadox Creek modeled flow duration versus USGS Gaging Station #01485500 data from 10/1/2002 to 9/30/2007 for validation.

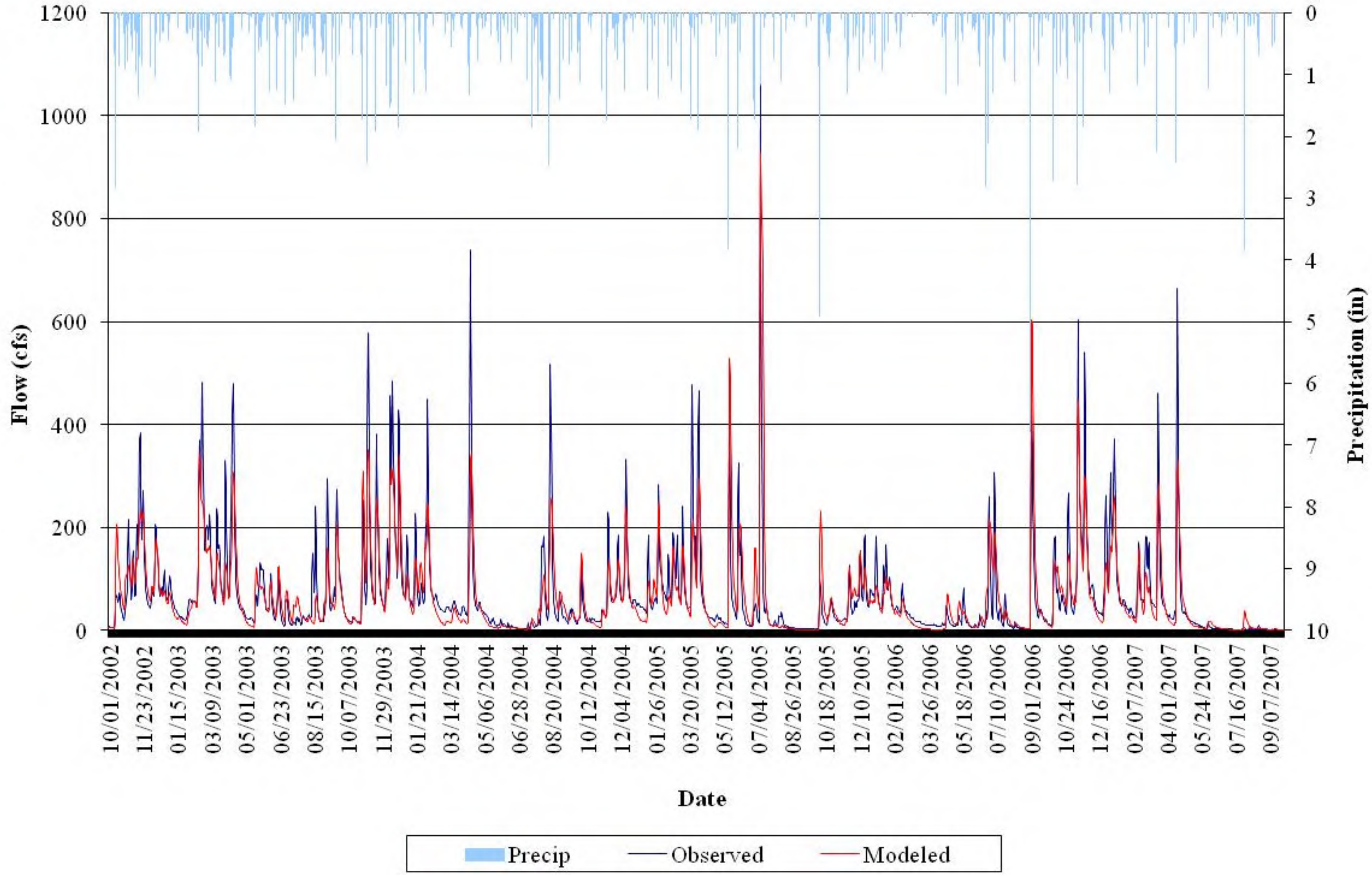

Figure B. 14 Nassawadox Creek modeled results versus USGS Gaging Station #01485500 data from 10/1/2002 to 9/30/2002 for validation.

B.7.2. Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors. First, water quality (*E. coli*) concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of *E. coli* is particularly variable. Variability in location and timing of fecal deposition, variability in the density of bacteria in feces (among species and for an individual animal), environmental impacts on re-growth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling *E. coli* concentrations. Additionally, the VADEQ data were censored at specific high and low values (e.g. 8,000 cfu/100ml or 16,000 cfu/100ml as high or 100 cfu/100ml as low value). Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

Five parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), the rate of surface runoff that will remove 90% of stored fecal bacteria per hour (WSQOP), the temperature correction coefficient for first-order decay of quality (THFST), and the concentration of fecal bacteria in interflow (IOQC). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established. Depending on the type of available bacteria data, either fecal coliform or *E. coli* monitored data were used. **Table B. 13** shows the model parameters utilized in calibration with their typical ranges, initial estimates, and final calibrated values. Water quality calibration was conducted for the period of October 2003 through September 2007. Validation was conducted from October 1999 through September 2003.

Table B. 13 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range	Initial Parameter Estimates	Calibrated Parameter Value
MON-SQOLIM	FC/ac	0.01 - 1.0E+30	0 - 7.8E+9	0 - 7.8E+9
WSQOP	in/hr	0.05 - 3.00	0 - 2.8	0 - 2.8
FSTDEC	1/day	0.01 - 10.00	1	10 - 27.5
THFST	n/a	1.0 - 2.0	1.07	1
IOQC	FC/ft^3	variable	1000	0 - 8E+8

Figure B. 15 and **Figure B. 16**, **Figure B. 17** and **Figure B. 18** show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the modeled values are daily averages based on hourly modeling. The monitored values may have been sampled at the highest concentration of the day and thus correctly appear above the modeled daily average. Although the range of modeled daily average values may not reach every instantaneous monitored value, the modeled data follows the trend of monitored data, and typically includes the monitored extremes.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process.

Table B. 14 shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the Red Bank Creek and Machipongo River watersheds stream segments.

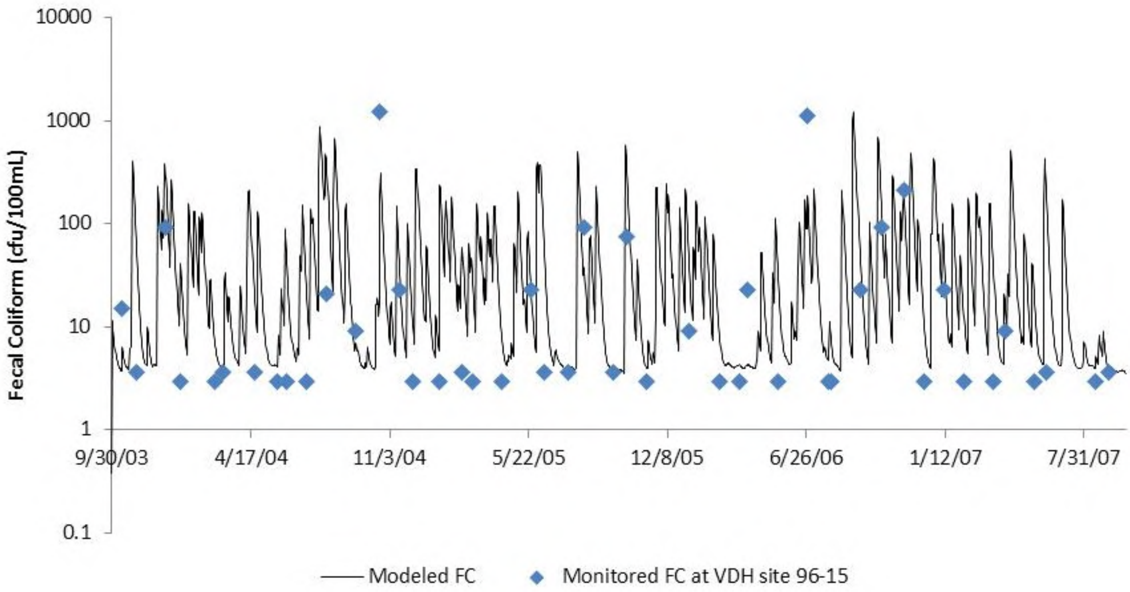

Figure B. 15 Fecal coliform calibration for 10/1/2003 to 9/30/2007 for VDH station 96-15 at the outlet of subwatershed 1 on the Machipongo River.

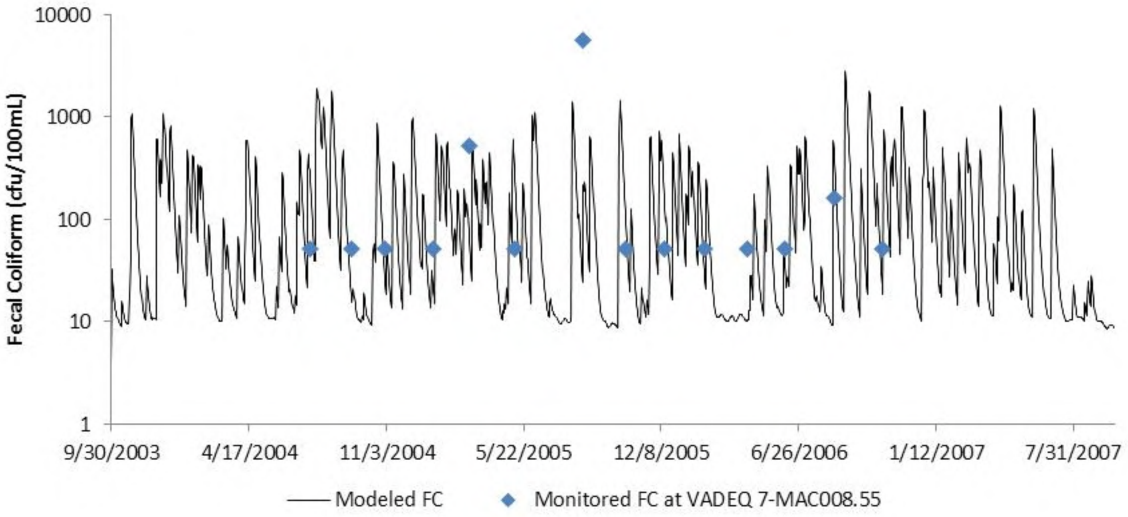

Figure B. 16 Fecal coliform calibration for 10/1/2003 to 9/30/2007 for VADEQ station 7-MAC008.55 at the outlet of subwatershed 2 on the Machipongo River. Monitored FC values translated from monitored *enterococci* data.

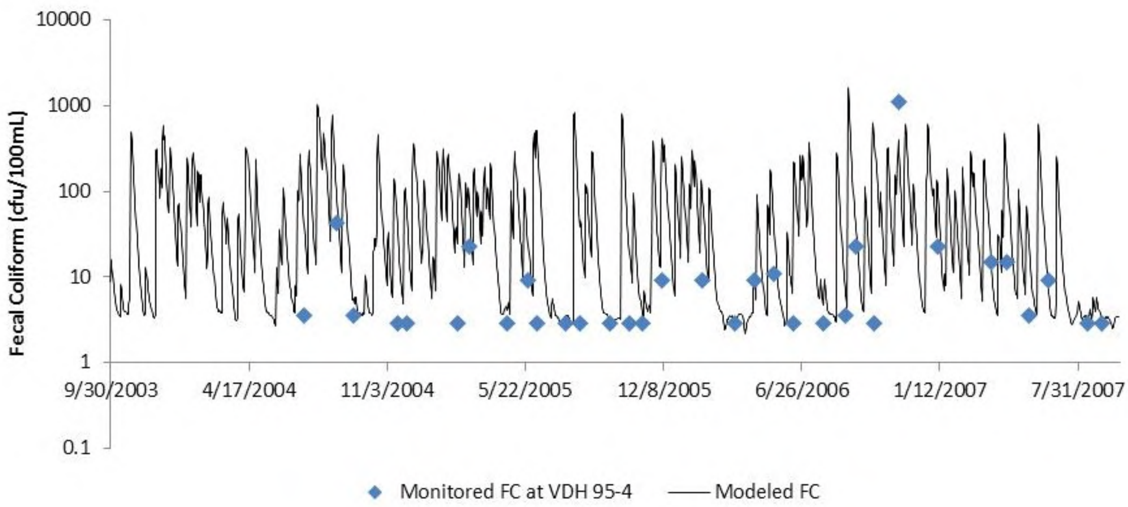

Figure B. 17 Fecal coliform calibration for 10/1/2003 to 9/30/2007 for VDH station 95-4 at the outlet of subwatershed 3 on Red Bank Creek.

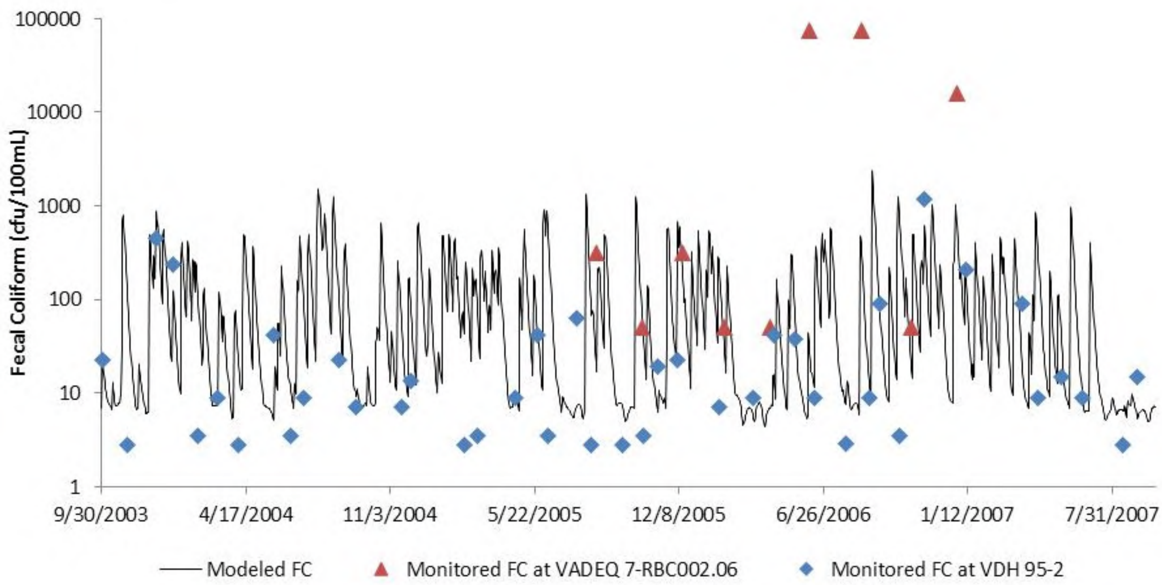

Figure B. 18 Fecal coliform calibration for 10/1/2003 to 9/30/2007 for VADEQ station 7-RBC002.06 and VDH station 95-2 at the outlet of subwatershed 5 on Red Bank Creek. Monitored FC values from VADEQ station translated from monitored *enterococci* data.

Table B. 14 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the calibration period.

Station ID	**Subwatershed**	**Number of Monitored Samples**	**Maximum Value** (cfu/100mL)		**30-Month Geometric Mean** (cfu/100mL)		**30-Month 90th Percentile** (cfu/100mL)	
			Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
96-15	1	46	1200	1232	8.46	21	93	150
95-RB-1	4	42	1200	1763.6	13.9	34.9	75	226.5
95-RB-2	5	42	1200	2349.3	14.2	45.2	93	360.7
95-RB-3*	5	42	1200	2349.3	21	45.2	144.3	360.7
95-RB-4	3	33	1100	1612.9	6.4	25.6	23	213.5

*Station within the watershed, not at the outlet.

Figure B. 19 and **Figure B. 20** show the results of water quality validation. **Table B. 15** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the Red Bank Creek-Machipongo River watershed stream segments.

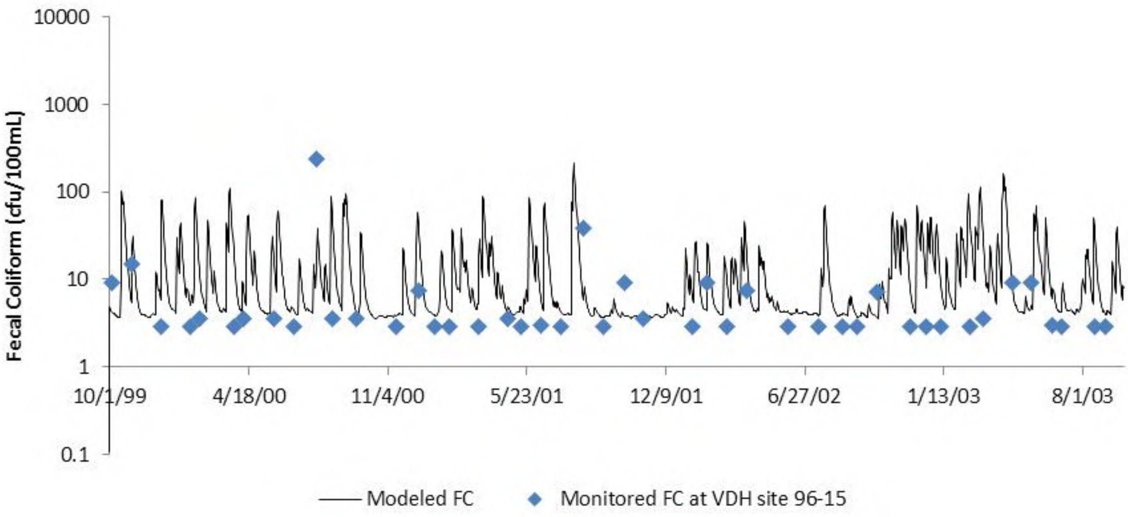

Figure B. 19 Fecal coliform validation for 10/1/1999 to 9/30/2003 for VDH station 96-15 at the outlet of subwatershed 1 on the Machipongo River.

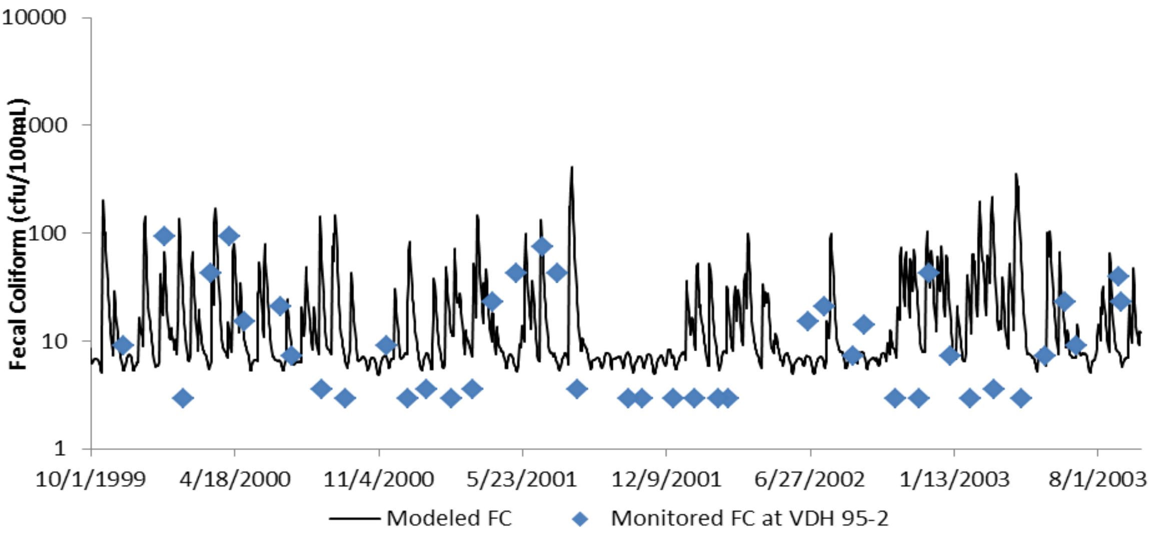

Figure B. 20 Fecal coliform validation for 10/1/1999 to 9/30/2003 for VDH station 95-2 at the outlet of subwatershed 5 on Red Bank Creek.

Table B. 15 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period.

Station ID	Subwatershed	Number of Monitored Samples	Maximum Value (cfu/100mL)		30-Month Geometric Mean (cfu/100mL)		30-Month 90th Percentile (cfu/100mL)	
			Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
96-15	1	45	240	789	4.42	13.5	9.1	93.8
95-RB-1	4	42	75	1233.5	1.6	23.5	23	154.1
95-RB-2	5	42	93	1871	2.1	27.6	43	250
95-RB-3*	5	42	150	1871	2.8	27.6	43	250

*Station within the watershed, not at the outlet.

B.8. Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (e.g. seasonal and spatial variability of waster production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

B.8.1. Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in **Table B. 16**, with base values for the model runs given. The parameters were adjusted to -50%, -10%, +10%, and +50% of the base value, and the model was run for water years 2000 - 2003. Where an increase or decrease of 50% exceeded the possible ranges of values for a parameter, the maximum and/or minimum value was used and the parameter values used in the sensitivity analysis were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliform from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration, such as INFILT (infiltration), LZSN (lower zone storage), as well as LZETP (lower zone evapotranspiration), KVARY (non-linear groundwater recession flow parameter), and AGWRC (active groundwater recession coefficient). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows were AGWRC, DEEPFR (loss to inactive groundwater), KVARY, LZETP, and INFILT. The responses of these and other hydrologic outputs are reported in **Table B. 17**.

Table B. 16 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	4.9
INFILT	Soil Infiltration Capacity	in/hr	0.0256 - 0.2231
BASETP	Base Flow Evapotranspiration	---	0.01
INTFW	Interflow Inflow	---	2
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.32
AGWRC	Groundwater Recession rate	---	0.92
KVARY	Groundwater Recession Flow	1/in	0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0 - 0.3
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.02 - 0.05
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0 – 0.8

Table B. 17 HSPF sensitivity analysis results for hydrologic model parameters.

Model Parameter	Parameter Change (%)	Percent Change in: Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC*	0.85	0.43	7.06	-17.91	1.63	-1.24	0.18	1.25	1.17
AGWRC*	0.88	0.25	4.27	-11.78	1.16	-0.88	-0.07	0.84	0.84
AGWRC*	0.96	-0.36	-4.92	22.43	-3.55	2.52	1.13	-1.44	-3.65
AGWRC*	0.999	-17.50	-18.46	43.77	-28.63	-21.80	-3.32	-13.01	-44.51
BASETP	-50	0.58	-0.09	2.74	0.13	0.95	0.97	0.25	0.28
BASETP	-10	0.11	-0.02	0.53	0.03	0.19	0.19	0.05	0.07
BASETP	10	-0.11	0.02	-0.52	-0.02	-0.19	-0.18	-0.05	-0.07
BASETP	50	-0.55	0.09	-2.52	-0.12	-0.94	-0.90	-0.24	-0.37
DEEPFR	-50	13.12	7.30	15.56	14.36	13.90	10.97	12.89	12.82
DEEPFR	-10	2.62	1.47	2.91	2.87	2.76	2.19	2.57	2.56
DEEPFR	10	-2.61	-1.47	-2.89	-2.88	-2.76	-2.18	-2.57	-2.56
DEEPFR	50	-13.02	-7.39	-15.72	-14.39	-13.64	-10.89	-12.78	-12.75
INFILT	-50	7.78	24.97	-11.45	7.36	5.19	9.36	9.92	8.27
INFILT	-10	1.10	3.52	-1.54	1.13	0.60	1.46	1.28	1.18
INFILT	10	-0.97	-3.06	1.40	-0.91	-0.58	-1.35	-1.13	-1.05
INFILT	50	-3.86	-12.08	5.90	-3.70	-2.24	-5.57	-4.19	-4.16
INTFW	-50	-0.56	4.69	-0.39	-0.37	-0.60	-0.65	-0.66	-0.57
INTFW	-10	-0.08	0.47	-0.04	-0.04	-0.08	-0.11	-0.07	-0.08
INTFW	10	0.07	-0.36	0.04	0.05	0.07	0.09	0.05	0.07
INTFW	50	0.27	-1.08	0.09	0.19	0.31	0.38	0.18	0.27
LZSN	-50	8.91	8.96	0.46	14.39	-2.00	7.61	17.08	9.11
LZSN	-10	1.25	1.49	-0.26	2.12	0.02	0.18	2.89	1.30
LZSN	10	-1.05	-1.25	0.42	-1.82	-0.16	0.39	-2.79	-1.11
LZSN	50	-4.11	-4.86	1.91	-7.62	-1.48	3.59	-11.64	-4.37
CEPSC	-50	2.65	1.32	4.68	2.38	6.34	1.15	-0.04	2.54
CEPSC	-10	0.51	0.31	0.88	0.39	1.36	0.19	-0.04	0.50
CEPSC	10	-0.44	-0.18	-0.87	-0.36	-1.05	-0.26	0.02	-0.43
CEPSC	50	-1.96	-0.36	-4.04	-1.21	-4.19	-1.97	-0.10	-1.90
LZETP	-50	26.33	21.64	33.45	16.01	16.88	44.94	31.24	25.15
LZETP	-10	2.95	2.46	3.75	2.40	1.74	4.40	3.61	2.90
LZETP	10	-2.49	-2.11	-2.86	-2.00	-1.52	-3.93	-2.73	-2.48
LZETP	50	-12.37	-12.15	-11.63	-6.99	-7.27	-27.08	-9.32	-12.44
KVARY*	0.5	0.08	5.63	-12.98	1.26	-1.10	-0.45	0.62	0.69
KVARY*	1	0.21	9.48	-20.37	1.80	-1.49	-0.45	1.00	0.99
KVARY*	2	0.46	15.02	-28.42	2.43	-1.96	-0.02	1.44	1.38
KVARY*	5	0.46	15.02	-28.42	2.43	-1.96	-0.02	1.44	1.38
UZSN	-50	3.54	3.56	4.08	3.21	3.26	3.38	4.55	3.29
UZSN	-10	0.72	0.86	0.51	0.48	0.62	0.94	0.94	0.71
UZSN	10	-0.64	-0.72	-0.33	-0.30	-0.56	-0.97	-0.85	-0.63
UZSN	50	-2.85	-2.84	-2.27	-1.53	-1.94	-4.51	-3.93	-2.77

*Actual parameter value used rather than percent change.

B.8.2. Water Quality Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 2000 – 2003 and model parameters established for 2012 conditions. The three HSPF parameters impacting the model's water quality response (**Table B. 18**) were increased and decreased by amounts that were consistent with the range of values for the parameter. FSTDEC (first order decay) was the parameter with the greatest influence on monthly geometric mean concentration (**Table B. 19**). The reason behind the more pronounced impact of change in decay rate on concentration of bacteria in the stream is that changes in decay rate impact bacteria from nonpoint as well as point sources and direct-nonpoint sources. On the other hand, changes in maximum fecal coliform accumulation on the land (MON-SQOLIM) and wash-off rate for fecal coliform on land surface (WSQOP) only impact the nonpoint portion of the bacteria. Graphical depictions of the results of this sensitivity analysis can be seen in **Figure B. 21**, **Figure B. 22**, **Figure B. 23**, and **Figure B. 24**.

Table B. 18 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0 - 7.8E9
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0 - 2.8
FSTDEC	In-stream First Order Decay Rate	1/day	10 - 27.5

Table B. 19 Percent change in 30-month fecal coliform geometric mean.

Model Parameter	Parameter Change (%)	Percent Change in 30-Month Geometric Mean
FSTDEC	-50	9.52E+01
FSTDEC	-10	1.29E+01
FSTDEC	10	-1.10E+01

FSTDEC	50	-4.21E+01
SQOLIM	-50	-7.07E-04
SQOLIM	-10	-1.15E-04
SQOLIM	10	5.29E-05
SQOLIM	50	7.62E-04
WSQOP	-50	7.97E-04
WSQOP	-10	1.02E-04
WSQOP	10	-8.70E-05
WSQOP	50	-3.35E-04

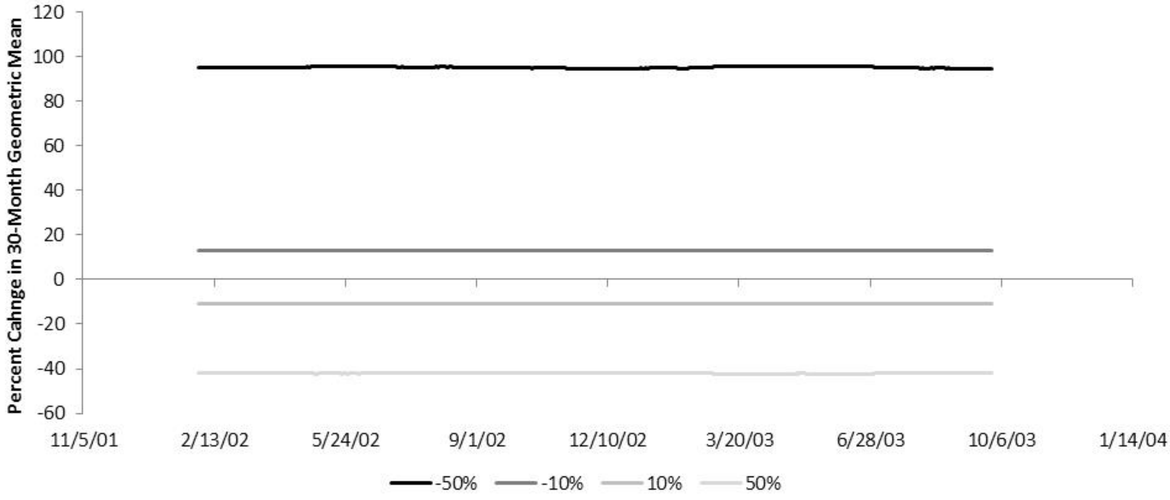

Figure B. 21 Results of sensitivity analysis on 30-month fecal coliform geometric mean concentrations as affected by changes to the in-stream first order decay rate (FSTDEC).

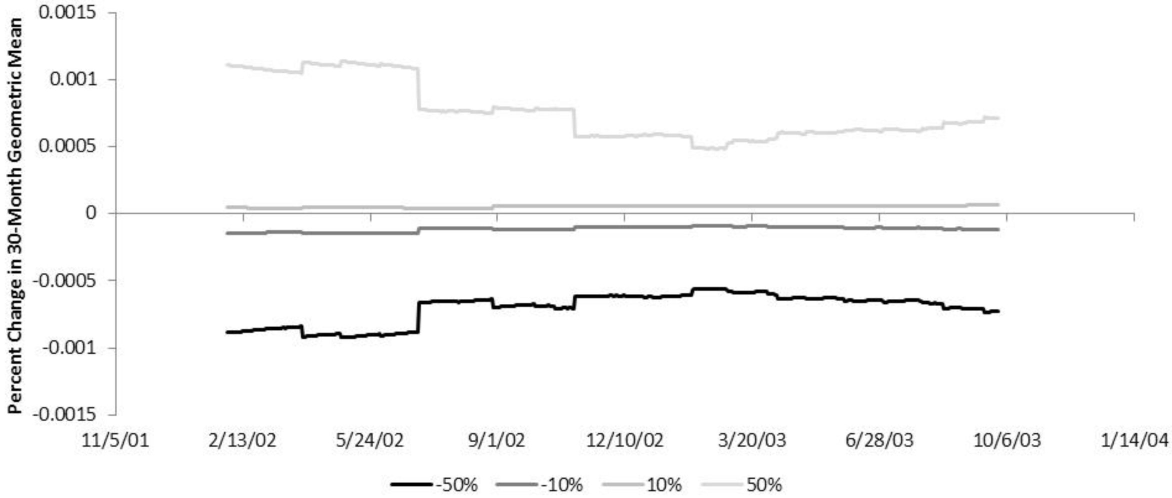

Figure B. 22 Results of sensitivity analysis on 30-month fecal coliform geometric mean concentrations as affected by changes to the maximum fecal coliform accumulation on land (MON-SQOLIM).

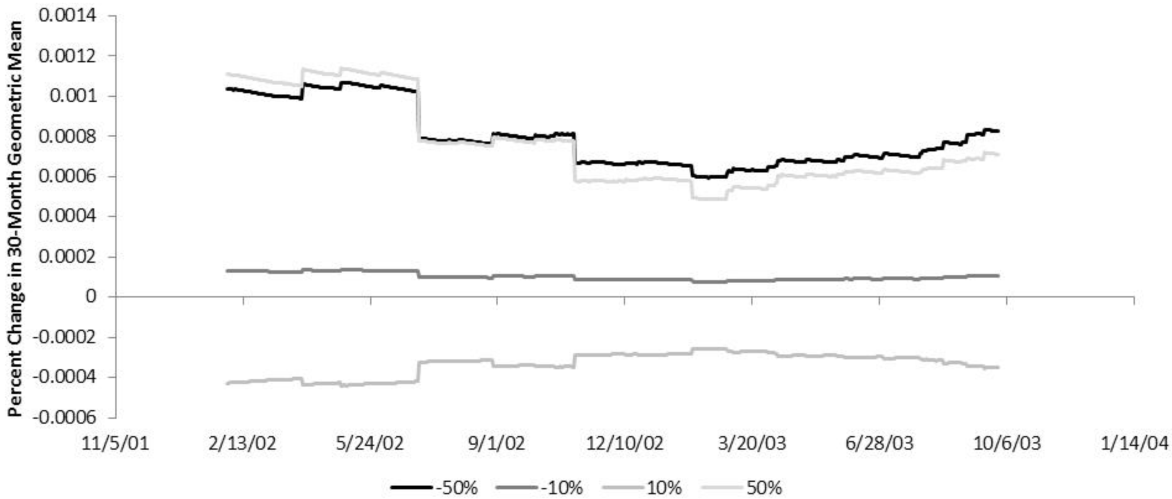

Figure B. 23 Results of sensitivity analysis on 30-month fecal coliform geometric mean concentrations as affected by changes to the wash off rate from land surfaces (WSQOP).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. It is evident in **Figure B. 24** that the model predicts a linear relationship between increased fecal coliform concentrations in direct applications and total load reaching the stream, while the upper end of increasing land-based application causes a significant spike in response in the stream. In **Figure B. 25**, it can be seen that the magnitude of this relationship differs between land applied and direct loadings, with a less pronounced response to changes in direct loads. Both direct loads and land applied loads have a significant impact on the geometric mean concentrations.

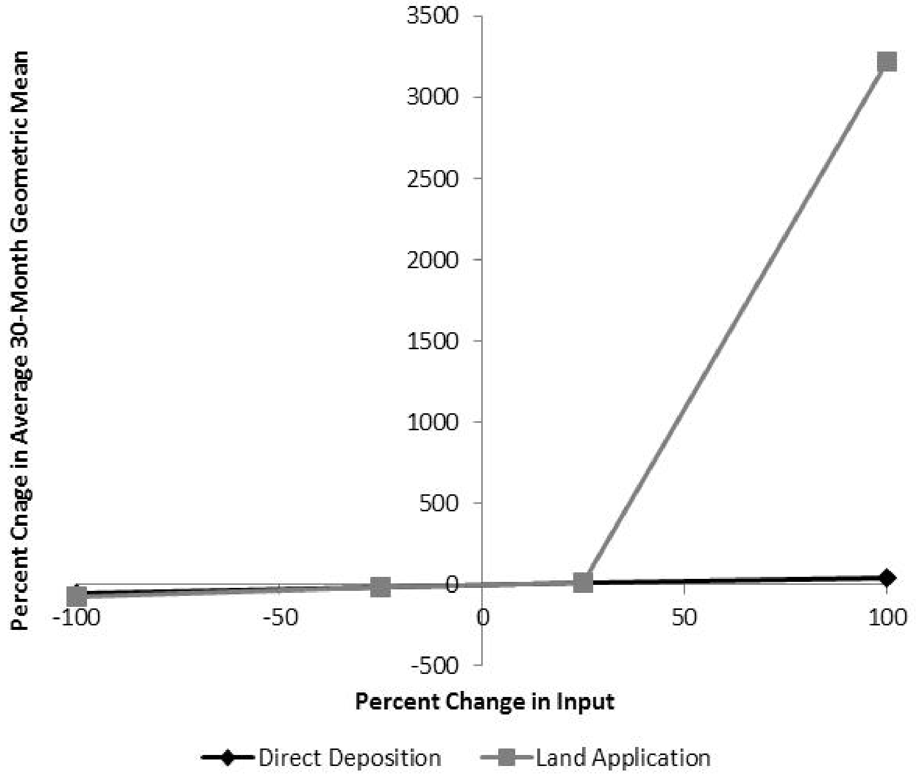

Figure B. 24 Results of total loading sensitivity analysis for outlet of the Red Bank Creek watershed study area.

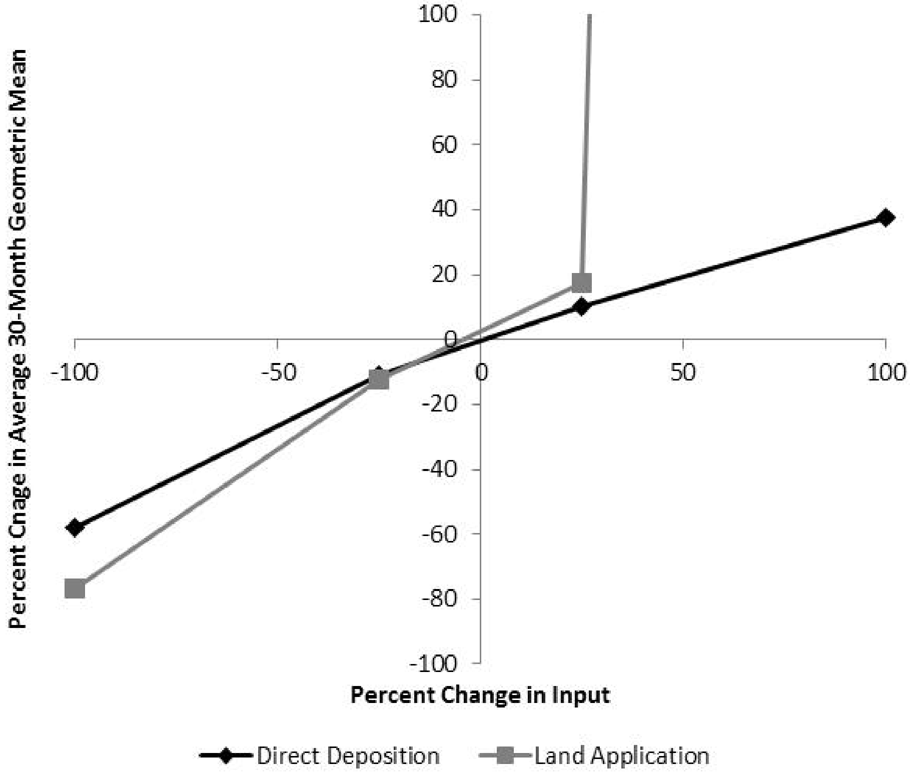

Figure B. 25 Results of total loading sensitivity analysis for outlet of the Red Bank Creek watershed study area at a more pronounced view.

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APPENDIX C

Current Conditions Fecal Coliform Loads

Current Conditions Fecal Coliform Loads

Table C. 1 Current conditions of land applied fecal coliform load for the Red Bank Creek and Machipongo River watershed study area.

Land-use	Jan	Feb	Mar	Apr	May	Jun
Pasture	6.47E+12	5.85E+12	6.46E+12	6.23E+12	6.44E+12	6.22E+12
Crop	1.12E+13	1.02E+13	1.12E+13	1.09E+13	1.12E+13	1.09E+13
Wetland	2.64E+13	2.39E+13	2.64E+13	2.56E+13	2.64E+13	2.56E+13
Barren	1.34E+10	1.21E+10	1.34E+10	1.30E+10	1.34E+10	1.30E+10
Forest	7.21E+12	6.51E+12	7.21E+12	6.97E+12	7.21E+12	6.97E+12
Commercial	9.78E+10	8.83E+10	9.78E+10	9.46E+10	9.78E+10	9.46E+10
LAX	7.24E+10	6.54E+10	8.32E+10	9.37E+10	9.69E+10	1.04E+11
Developed	2.44E+12	2.20E+12	2.44E+12	2.36E+12	2.44E+12	2.36E+12

Table C. 1 Current conditions of land applied fecal coliform load for the Red Bank Creek and Machipongo River watershed study area (continued).

Land-use	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Pasture	6.43E+12	6.43E+12	6.23E+12	6.46E+12	6.25E+12	6.47E+12	7.59E+13
Crop	1.12E+13	1.12E+13	1.09E+13	1.12E+13	1.09E+13	1.12E+13	1.32E+14
Wetland	2.64E+13	2.64E+13	2.56E+13	2.64E+13	2.56E+13	2.64E+13	3.11E+14
Barren	1.34E+10	1.34E+10	1.30E+10	1.34E+10	1.30E+10	1.34E+10	1.58E+11
Forest	7.21E+12	7.21E+12	6.97E+12	7.21E+12	6.97E+12	7.21E+12	8.49E+13
Commercial	9.78E+10	9.78E+10	9.46E+10	9.78E+10	9.46E+10	9.78E+10	1.15E+12
LAX	1.08E+11	1.08E+11	9.37E+10	8.32E+10	8.05E+10	7.24E+10	1.06E+12
Developed	2.44E+12	2.44E+12	2.36E+12	2.44E+12	2.36E+12	2.44E+12	2.87E+13

Table C. 2 Current conditions of land applied fecal coliform load for the Machipongo River watershed by land-use (subwatershed 1, 2).

Land-use	Jan	Feb	Mar	Apr	May	Jun
Barren	1.34E+10	1.21E+10	1.34E+10	1.30E+10	1.34E+10	1.30E+10
Forest	6.55E+12	5.92E+12	6.55E+12	6.34E+12	6.55E+12	6.34E+12
Pasture	5.01E+12	4.53E+12	5.01E+12	4.84E+12	5.00E+12	4.83E+12
Commercial	9.08E+10	8.20E+10	9.08E+10	8.79E+10	9.08E+10	8.79E+10
LAX	3.99E+10	3.60E+10	4.32E+10	4.58E+10	4.74E+10	4.90E+10
Developed	2.00E+12	1.81E+12	2.00E+12	1.94E+12	2.00E+12	1.94E+12
Crop	8.90E+12	8.04E+12	8.90E+12	8.61E+12	8.90E+12	8.61E+12
Wetland	2.33E+13	2.10E+13	2.33E+13	2.25E+13	2.33E+13	2.25E+13

Table C. 2 Current conditions of land applied fecal coliform load for the Machipongo River watershed by land-use (subwatershed 1, 2) (continued).

Land-use	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	1.34E+10	1.34E+10	1.30E+10	1.34E+10	1.30E+10	1.34E+10	1.58E+11
Forest	6.55E+12	6.55E+12	6.34E+12	6.55E+12	6.34E+12	6.55E+12	7.72E+13
Pasture	4.99E+12	4.99E+12	4.84E+12	5.01E+12	4.84E+12	5.01E+12	5.89E+13
Commercial	9.08E+10	9.08E+10	8.79E+10	9.08E+10	8.79E+10	9.08E+10	1.07E+12
LAX	5.07E+10	5.07E+10	4.58E+10	4.32E+10	4.18E+10	3.99E+10	5.33E+11
Developed	2.00E+12	2.00E+12	1.94E+12	2.00E+12	1.94E+12	2.00E+12	2.36E+13
Crop	8.90E+12	8.90E+12	8.61E+12	8.90E+12	8.61E+12	8.90E+12	1.05E+14
Wetland	2.33E+13	2.33E+13	2.25E+13	2.33E+13	2.25E+13	2.33E+13	2.74E+14

Table C. 3 Current conditions of land applied fecal coliform load for the Red Bank Creek riverine reaches by land-use (subwatershed 7, 9).

Land-use	Jan	Feb	Mar	Apr	May	Jun
Wetland	2.22E+12	2.01E+12	2.22E+12	2.15E+12	2.22E+12	2.15E+12
Forest	5.79E+11	5.23E+11	5.79E+11	5.60E+11	5.79E+11	5.60E+11
Pasture	1.44E+12	1.30E+12	1.44E+12	1.38E+12	1.43E+12	1.37E+12
Commercial	6.96E+09	6.29E+09	6.96E+09	6.74E+09	6.96E+09	6.74E+09
LAX	3.26E+10	2.94E+10	4.00E+10	4.79E+10	4.95E+10	5.51E+10
Developed	4.00E+11	3.61E+11	4.00E+11	3.87E+11	4.00E+11	3.87E+11
Crop	2.25E+12	2.03E+12	2.25E+12	2.18E+12	2.25E+12	2.18E+12

Table C. 3 Current conditions of land applied fecal coliform load for the Red Bank Creek riverine reaches by land-use (subwatershed 7, 9) (continued).

Land-use	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Wetland	2.22E+12	2.22E+12	2.15E+12	2.22E+12	2.15E+12	2.22E+12	2.61E+13
Forest	5.79E+11	5.79E+11	5.60E+11	5.79E+11	5.60E+11	5.79E+11	6.82E+12
Pasture	1.42E+12	1.42E+12	1.38E+12	1.44E+12	1.39E+12	1.44E+12	1.68E+13
Commercial	6.96E+09	6.96E+09	6.74E+09	6.96E+09	6.74E+09	6.96E+09	8.20E+10
LAX	5.70E+10	5.70E+10	4.79E+10	4.00E+10	3.87E+10	3.26E+10	5.28E+11
Developed	4.00E+11	4.00E+11	3.87E+11	4.00E+11	3.87E+11	4.00E+11	4.71E+12
Crop	2.25E+12	2.25E+12	2.18E+12	2.25E+12	2.18E+12	2.25E+12	2.65E+13

Table C. 4 Current conditions of land applied fecal coliform load for the Red Bank Creek tidal reaches by land-use (subwatershed 3, 4, 5, 6, 8).

Land-use	Jan	Feb	Mar	Apr	May	Jun
Wetland	9.35E+11	8.44E+11	9.35E+11	9.04E+11	9.35E+11	9.04E+11
Forest	7.46E+10	6.74E+10	7.46E+10	7.22E+10	7.46E+10	7.22E+10
Pasture	1.76E+10	1.59E+10	1.76E+10	1.71E+10	1.76E+10	1.71E+10
Developed	3.62E+10	3.27E+10	3.62E+10	3.50E+10	3.62E+10	3.50E+10
Crop	9.58E+10	8.65E+10	9.58E+10	9.27E+10	9.58E+10	9.27E+10

Table C. 4 Current conditions of land applied fecal coliform load for the Red Bank Creek tidal reaches by land-use (subwatershed 3, 4, 5, 6, 8) (continued).

Land-use	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Wetland	9.35E+11	9.35E+11	9.04E+11	9.35E+11	9.04E+11	9.35E+11	1.10E+13
Forest	7.46E+10	7.46E+10	7.22E+10	7.46E+10	7.22E+10	7.46E+10	8.78E+11
Pasture	1.76E+10	1.76E+10	1.71E+10	1.76E+10	1.71E+10	1.76E+10	2.08E+11
Developed	3.62E+10	3.62E+10	3.50E+10	3.62E+10	3.50E+10	3.62E+10	4.26E+11
Crop	9.58E+10	9.58E+10	9.27E+10	9.58E+10	9.27E+10	9.58E+10	1.13E+12

Table C. 5 Monthly, directly deposited fecal coliform loads for the Red Bank Creek and Machipongo River watershed study area, reach 1, 2, 3, 4, 5.

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	1	8.23E+11	7.43E+11	8.23E+11	7.96E+11	8.23E+11	7.96E+11
Livestock	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	1	8.03E+10	7.25E+10	8.03E+10	7.77E+10	8.03E+10	7.77E+10
Human/Pet	2	1.74E+12	1.57E+12	1.74E+12	1.68E+12	1.74E+12	1.68E+12
Livestock	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	2	2.41E+11	2.18E+11	2.41E+11	2.33E+11	2.41E+11	2.33E+11
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	3	3.46E+09	3.12E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	4	1.39E+09	1.25E+09	1.39E+09	1.34E+09	1.39E+09	1.34E+09
Human/Pet	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	5	3.46E+09	3.12E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09

Table C. 5 Monthly, directly deposited fecal coliform loads for the Red Bank Creek and Machipongo River watershed study area, reach 1, 2, 3, 4, 5 (continued).

Source Type	Reach ID	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human/Pet	1	8.23E+11	8.23E+11	7.96E+11	8.23E+11	7.96E+11	8.23E+11	9.69E+12
Livestock	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	1	8.03E+10	8.03E+10	7.77E+10	8.03E+10	7.77E+10	8.03E+10	9.45E+11
Human/Pet	2	1.74E+12	1.74E+12	1.68E+12	1.74E+12	1.68E+12	1.74E+12	2.04E+13
Livestock	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	2	2.41E+11	2.41E+11	2.33E+11	2.41E+11	2.33E+11	2.41E+11	2.84E+12
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	3	3.46E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09	3.46E+09	4.07E+10
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	4	1.39E+09	1.39E+09	1.34E+09	1.39E+09	1.34E+09	1.39E+09	1.64E+10
Human/Pet	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	5	3.46E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09	3.46E+09	4.07E+10

Table C. 6 Monthly, directly deposited fecal coliform loads for the Red Bank Creek and Machipongo River watershed study area, reach 6, 7, 8, 9.

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	6	2.57E+09	2.32E+09	2.57E+09	2.49E+09	2.57E+09	2.49E+09
Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	7	2.17E+08	1.96E+08	2.89E+08	4.20E+08	4.34E+08	4.90E+08
Wildlife	7	1.20E+10	1.08E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	8	2.98E+09	2.69E+09	2.98E+09	2.88E+09	2.98E+09	2.88E+09
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	4.34E+08	3.92E+08	5.79E+08	8.40E+08	8.68E+08	9.80E+08
Wildlife	9	3.21E+10	2.90E+10	3.21E+10	3.11E+10	3.21E+10	3.11E+10

Table C. 6 Monthly, directly deposited fecal coliform loads for the Red Bank Creek and Machipongo River watershed study area, reach 6, 7, 8, 9 (continued).

Source Type	Reach ID	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human/Pet	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	6	2.57E+09	2.57E+09	2.49E+09	2.57E+09	2.49E+09	2.57E+09	3.03E+10
Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	7	5.06E+08	5.06E+08	4.20E+08	2.89E+08	2.80E+08	2.17E+08	4.27E+09
Wildlife	7	1.20E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10	1.20E+10	1.41E+11
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	8	2.98E+09	2.98E+09	2.88E+09	2.98E+09	2.88E+09	2.98E+09	3.51E+10
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	1.01E+09	1.01E+09	8.40E+08	5.79E+08	5.60E+08	4.34E+08	8.53E+09
Wildlife	9	3.21E+10	3.21E+10	3.11E+10	3.21E+10	3.11E+10	3.21E+10	3.78E+11

Table C. 7 Monthly, directly deposited fecal coliform loads in each reach of the Machipongo River watershed (reach 1, 2).

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	1	8.23E+11	7.43E+11	8.23E+11	7.96E+11	8.23E+11	7.96E+11
Livestock	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	1	8.03E+10	7.25E+10	8.03E+10	7.77E+10	8.03E+10	7.77E+10
Human/Pet	2	1.74E+12	1.57E+12	1.74E+12	1.68E+12	1.74E+12	1.68E+12
Livestock	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	2	2.41E+11	2.18E+11	2.41E+11	2.33E+11	2.41E+11	2.33E+11

Table C. 7 Monthly, directly deposited fecal coliform loads in each reach of the Machipongo River watershed (reach 1, 2) (continued).

Source Type	Reach ID	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human/Pet	1	8.23E+11	8.23E+11	7.96E+11	8.23E+11	7.96E+11	8.23E+11	9.69E+12
Livestock	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	1	8.03E+10	8.03E+10	7.77E+10	8.03E+10	7.77E+10	8.03E+10	9.45E+11
Human/Pet	2	1.74E+12	1.74E+12	1.68E+12	1.74E+12	1.68E+12	1.74E+12	2.04E+13
Livestock	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	2	2.41E+11	2.41E+11	2.33E+11	2.41E+11	2.33E+11	2.41E+11	2.84E+12

Table C. 8 Monthly, directly deposited fecal coliform loads in each reach of the Red Bank Creek riverine reaches (reach 7, 9).

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	7	2.17E+08	1.96E+08	2.89E+08	4.20E+08	4.34E+08	4.90E+08
Wildlife	7	1.20E+10	1.08E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	4.34E+08	3.92E+08	5.79E+08	8.40E+08	8.68E+08	9.80E+08
Wildlife	9	3.21E+10	2.90E+10	3.21E+10	3.11E+10	3.21E+10	3.11E+10

Table C. 8 Monthly, directly deposited fecal coliform loads in each reach of the Red Bank Creek riverine reaches (reach 7, 9) (continued).

Source Type	Reach ID	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human/Pet	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	7	5.06E+08	5.06E+08	4.20E+08	2.89E+08	2.80E+08	2.17E+08	4.27E+09
Wildlife	7	1.20E+10	1.20E+10	1.16E+10	1.20E+10	1.16E+10	1.20E+10	1.41E+11
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	1.01E+09	1.01E+09	8.40E+08	5.79E+08	5.60E+08	4.34E+08	8.53E+09
Wildlife	9	3.21E+10	3.21E+10	3.11E+10	3.21E+10	3.11E+10	3.21E+10	3.78E+11

Table C. 9 Monthly, directly deposited fecal coliform loads in each reach of the Red Bank Creek tidal reaches (reach 3, 4, 5, 6, 8).

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	3	3.46E+09	3.12E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	4	1.39E+09	1.25E+09	1.39E+09	1.34E+09	1.39E+09	1.34E+09
Human/Pet	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	5	3.46E+09	3.12E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09
Human/Pet	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	6	2.57E+09	2.32E+09	2.57E+09	2.49E+09	2.57E+09	2.49E+09
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	8	2.98E+09	2.69E+09	2.98E+09	2.88E+09	2.98E+09	2.88E+09

Table C. 9 Monthly, directly deposited fecal coliform loads in each reach of the Red Bank Creek tidal reaches (reach 3, 4, 5, 6, 8) (continued).

Source Type	Reach ID	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	3	3.46E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09	3.46E+09	4.07E+10
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	4	1.39E+09	1.39E+09	1.34E+09	1.39E+09	1.34E+09	1.39E+09	1.64E+10
Human/Pet	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	5	3.46E+09	3.46E+09	3.35E+09	3.46E+09	3.35E+09	3.46E+09	4.07E+10
Human/Pet	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	6	2.57E+09	2.57E+09	2.49E+09	2.57E+09	2.49E+09	2.57E+09	3.03E+10
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	8	2.98E+09	2.98E+09	2.88E+09	2.98E+09	2.88E+09	2.98E+09	3.51E+10

Table C. 10 Existing annual fecal coliform loads from land-based sources for the Red Bank Creek and Machipongo River watershed study area.

Source	Water	Forest	Commercial	Pasture	LAX	Developed	Crop	Wetland	Barren
Beaver	8.40E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef	1.28E+10	0.00E+00	0.00E+00	2.43E+12	1.15E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef Calves	0.00E+00	0.00E+00	0.00E+00	9.99E+11	4.74E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chicken	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Raccoon	0.00E+00	5.16E+13	1.12E+12	3.97E+13	2.44E+11	2.29E+13	8.05E+13	1.87E+14	1.02E+11
Deer	0.00E+00	2.59E+13	0.00E+00	2.12E+13	6.04E+10	2.92E+12	4.39E+13	8.13E+13	0.00E+00
Duck	0.00E+00	4.28E+08	1.67E+06	2.12E+08	1.51E+07	1.67E+08	4.66E+08	2.47E+09	3.24E+06
Goose	0.00E+00	2.28E+10	8.87E+07	1.13E+10	8.02E+08	8.90E+09	2.48E+10	1.31E+11	1.72E+08
Horse	0.00E+00	0.00E+00	0.00E+00	7.54E+12	3.22E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	7.38E+12	2.87E+10	3.66E+12	2.59E+11	2.88E+12	8.03E+12	4.25E+13	5.58E+10
Sheep	0.00E+00	0.00E+00	0.00E+00	3.90E+11	1.16E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight Pipes	3.01E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	4.39E+09	0.00E+00	9.00E+08	2.56E+06	0.00E+00	1.86E+09	1.38E+10	0.00E+00

Table C. 11 Existing annual fecal coliform loads from land-based sources for the Machipongo River watershed (subwatershed 1, 2).

Source	Water	Forest	Commercial	Pasture	LAX	Developed	Crop	Wetland	Barren
Beaver	5.99E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef Calves	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chicken	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Raccoon	0.00E+00	4.70E+13	1.04E+12	3.36E+13	1.65E+11	1.89E+13	6.35E+13	1.65E+14	1.02E+11
Deer	0.00E+00	2.37E+13	0.00E+00	1.79E+13	4.07E+10	2.43E+12	3.52E+13	7.33E+13	0.00E+00
Duck	0.00E+00	3.77E+08	1.67E+06	1.90E+08	1.02E+07	1.32E+08	3.56E+08	2.09E+09	3.24E+06
Goose	0.00E+00	2.01E+10	8.87E+07	1.01E+10	5.41E+08	7.04E+09	1.90E+10	1.11E+11	1.72E+08
Horse	0.00E+00	0.00E+00	0.00E+00	3.77E+12	1.43E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	6.50E+12	2.87E+10	3.28E+12	1.75E+11	2.28E+12	6.14E+12	3.60E+13	5.58E+10
Sheep	0.00E+00	0.00E+00	0.00E+00	3.41E+11	9.25E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight Pipes	3.01E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	4.02E+09	0.00E+00	7.59E+08	1.73E+06	0.00E+00	1.49E+09	1.24E+10	0.00E+00

Table C. 12 Existing annual fecal coliform loads from land-based sources for the Red Bank riverine reaches (subwatershed 7, 9).

Source	Water	Forest	Commercial	Pasture	LAX	Developed	Crop	Wetland	Barren
Beaver	1.75E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef	1.28E+10	0.00E+00	0.00E+00	2.43E+12	1.15E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef Calves	0.00E+00	0.00E+00	0.00E+00	9.99E+11	4.74E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chicken	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Raccoon	0.00E+00	4.01E+12	8.20E+10	5.93E+12	7.94E+10	3.73E+12	1.62E+13	1.62E+13	0.00E+00
Deer	0.00E+00	2.00E+12	0.00E+00	3.30E+12	1.97E+10	4.68E+11	8.49E+12	6.05E+12	0.00E+00
Duck	0.00E+00	4.64E+07	0.00E+00	2.10E+07	4.90E+06	2.97E+07	1.06E+08	2.23E+08	0.00E+00
Goose	0.00E+00	2.47E+09	0.00E+00	1.12E+09	2.61E+08	1.58E+09	5.67E+09	1.19E+10	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	3.77E+12	1.79E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	8.00E+11	0.00E+00	3.62E+11	8.44E+10	5.11E+11	1.83E+12	3.84E+12	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	4.87E+10	2.31E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight Pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	3.40E+08	0.00E+00	1.40E+08	8.34E+05	0.00E+00	3.60E+08	1.03E+09	0.00E+00

Table C. 13 Existing annual fecal coliform loads from land-based sources for the Red Bank tidal reaches (subwatershed 3, 4, 5, 6, 8).

Source	Water	Forest	Commercial	Pasture	LAX	Developed	Crop	Wetland	Barren
Beaver	6.57E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef Calves	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chicken	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Raccoon	0.00E+00	5.83E+11	0.00E+00	1.50E+11	0.00E+00	3.12E+11	8.38E+11	6.41E+12	0.00E+00
Deer	0.00E+00	2.19E+11	0.00E+00	3.73E+10	0.00E+00	2.33E+10	2.34E+11	1.95E+12	0.00E+00
Duck	0.00E+00	4.44E+06	0.00E+00	1.17E+06	0.00E+00	5.26E+06	3.20E+06	1.53E+08	0.00E+00
Goose	0.00E+00	2.37E+08	0.00E+00	6.24E+07	0.00E+00	2.80E+08	1.71E+08	8.12E+09	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	7.66E+10	0.00E+00	2.02E+10	0.00E+00	9.05E+10	5.52E+10	2.63E+12	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Straight Pipes	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	3.71E+07	0.00E+00	1.58E+06	0.00E+00	0.00E+00	9.93E+06	3.32E+08	0.00E+00

Table C. 14 Existing annual fecal coliform loads from direct-deposition sources for the Red Bank Creek and Machipongo River watershed study area.

Source	Annual Total Loads (cfu/yr)
Beaver	8.40E+09
Beef	1.28E+10
Beef Calves	0.00E+00
Chicken	0.00E+00
Raccoon	9.61E+11
Deer	4.39E+11
Duck	1.47E+08
Goose	5.14E+09
Horse	0.00E+00
Muskrat	3.05E+12
Sheep	0.00E+00
Straight Pipes	3.01E+13
Turkey	5.25E+07

Table C. 15 Existing annual fecal coliform loads from direct-deposition sources for the Machipongo River watershed (reach 1, 2).

Source	Annual Total Loads (cfu/yr)
Beaver	5.99E+09
Beef	0.00E+00
Beef Calves	0.00E+00
Chicken	0.00E+00
Raccoon	8.24E+11
Deer	3.82E+11
Duck	1.23E+08
Goose	4.32E+09
Horse	0.00E+00
Muskrat	2.57E+12
Sheep	0.00E+00
Straight Pipes	3.01E+13
Turkey	4.69E+07

Table C. 16 Existing annual fecal coliform loads from direct-deposition sources for the Red Bank Creek riverine reaches (reach 7, 9).

Source	Annual Total Loads (cfu/yr)
Beaver	1.75E+09
Beef	1.28E+10
Beef Calves	0.00E+00
Chicken	0.00E+00
Raccoon	1.16E+11
Deer	5.10E+10
Duck	1.68E+07
Goose	5.89E+08
Horse	0.00E+00
Muskrat	3.50E+11
Sheep	0.00E+00
Straight Pipes	0.00E+00
Turkey	4.68E+06

Table C. 17 Existing annual fecal coliform loads from direct-deposition sources for the Red Bank Creek tidal reaches (reach 3, 4, 5, 6, 8).

Source	Annual Total Loads (cfu/yr)
Beaver	6.57E+08
Beef	0.00E+00
Beef Calves	0.00E+00
Chicken	0.00E+00
Raccoon	2.08E+10
Deer	6.18E+09
Duck	6.49E+06
Goose	2.27E+08
Horse	0.00E+00
Muskrat	1.35E+11
Sheep	0.00E+00
Straight Pipes	0.00E+00
Turkey	9.53E+05